

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

TECHNOLOGY OF SALT MAKING IN THE
UNITED STATES

W. C. PHALEN

[In cooperation with the United States Geological Survey]



WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted, copies may be obtained at cost price only through the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Superintendent of Documents is *not an official of the Bureau of Mines*. His is an entirely separate office, and he should be addressed

SUPERINTENDENT OF DOCUMENTS,

Government Printing Office,

Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. The price of this publication is 25 cents.

II

First edition. November, 1917.

CONTENTS.

	Page.
Preface, by Van H. Manning.....	xi
Introduction.....	1
Field work done.....	1
Acknowledgments.....	2
Mineralogy of salt.....	3
The uses of salt.....	3
Types of occurrence.....	3
Salt deposits of the United States.....	5
General distribution and character.....	5
New York.....	6
Early developments.....	6
Relative importance of New York field.....	7
Position of field.....	7
Extent of deposits.....	8
Michigan.....	9
Relative importance of Michigan salt industry.....	9
Position of salt fields.....	9
Depth to salt beds.....	9
Ohio.....	11
Relative importance of Ohio salt industry.....	11
Position of fields.....	11
Salt deposits in northeastern Ohio.....	11
Brine horizon in southeastern Ohio.....	13
Character of brine.....	14
West Virginia.....	15
Position of salt fields.....	15
Kanawha River area.....	15
Pennsylvania.....	16
Situation of salt fields.....	16
Virginia.....	18
Kansas.....	19
Relative importance of Kansas salt industry.....	19
Position and extent of salt deposits.....	19
Louisiana.....	20
Relative importance of Louisiana salt production.....	20
Situation of deposits.....	20
Salines of northern Louisiana.....	20
Salines of southern Louisiana.....	21
Grande Cote (Weeks Island).....	21
Situation.....	21
Occurrence of salt.....	21
Petite Anse (Averys Island).....	22
Situation.....	22
Occurrence of salt.....	22

CONTENTS.

Salt deposits of the United States—Continued	Page.
Texas	23
Situation of salt-producing areas	23
Industrial development	24
Salines of eastern Texas	24
Situation	24
Grand Saline	24
Palestine	26
Ston Saline	26
Brooks Saline	26
Occurrences of salt in western Texas	27
Salt basin of Trans-Pecos region	27
Colorado City	28
Other occurrences of salt	28
Oklahoma	28
Relative importance of salt industry	28
Salt plains	29
Situation	29
Oregon	29
Idaho and Wyoming	29
Nevada	30
Relative importance of Nevada salt industry	30
New Mexico	30
Relative importance of salt output	30
Situation of deposits	30
Arizona	31
Utah	31
Relative importance of Utah salt industry	31
Salt-producing localities	32
Great Salt Lake	32
California	32
Relative importance of salt production	32
General occurrence of salt	32
Production of salt from sea water	33
Producing localities	33
Description of occurrences	33
Colusa County	33
Inyo County	34
Kern County	35
Mono County	35
San Bernardino County	35
San Luis Obispo County	36
Other localities	37
Salt-making processes	38
Classification	38
Solar evaporation	38
Where process is used	38
Solar evaporation at Syracuse, N. Y.	38
Commercial status of industry	38
Original method	39
Improved method	40
Recovery of sea salt in California	40
Production centers	40
Salt-making season	41

Salt-making processes—Continued	
Solar evaporation—Continued	
Recovery of sea salt in California—Continued	Page
Strength of brine.....	42
Salt ponds.....	42
Methods of pumping.....	44
Harvesting.....	44
Milling.....	46
Utilization of bittern.....	46
Notes on samples.....	48
Salt production at Great Salt Lake, Utah.....	49
Production centers.....	49
Character of brine.....	49
Salt making at Saltair.....	51
Principal methods of evaporating salt.....	52
Direct-heat evaporation.....	52
Evaporation in open-kettles.....	52
History.....	52
Construction of apparatus.....	53
Methods of operation.....	54
Evaporation in open pans.....	55
Preliminary treatment of the brine.....	55
Pan construction and manipulation.....	55
Character of product.....	57
Practice in Wyoming County, N. Y.....	57
Practice in Michigan.....	58
Practice near Hutchinson, Kans.....	59
Practice in Sevier Valley, Utah.....	60
Steam evaporation.....	61
Evaporation in jacketed kettles.....	61
Grainer process.....	61
General principles of saline deposition.....	61
General conditions as to use of waste heat.....	62
Manipulation of brine.....	63
Pumping.....	63
Clarifying.....	64
Preheating.....	64
Outline of process.....	65
Construction of grainer.....	66
Mechanical rakers.....	66
Belt conveyors.....	67
Alberger process.....	68
Practice in New York.....	69
Practice in Michigan.....	70
Development.....	70
Ludington-Manistee district.....	70
Saginaw Valley district.....	71
Detroit district.....	73
Practice in northeastern Ohio.....	74
Former practice at Pittsburgh, Pa.....	75
Practice in Kansas.....	76
Practice in Texas.....	76
Practice in West Virginia and southern Ohio.....	77
Salt-making centers.....	77
Peculiarities of brine.....	77

Steam evaporation—Continued	
Alberger process—Continued.	
Practice in West Virginia and southern Ohio—Continued	Page
Pretreatment in mud settlers.....	77
Re-treatment by filtration.....	79
Treatment at Malden, W. Va.....	79
Recovery of bromine.....	80
History.....	80
Production centers.....	81
Comments on the industry.....	84
Methods of making bromine.....	85
Periodic or intermittent process.....	85
Production of bromine in Ohio and West Virginia by intermittent process.....	85
Distillation of bromine in Michigan.....	87
Drawbacks to periodic process.....	88
Recent developments in preparing bromine.....	88
Continuous process.....	91
Electrolytic process.....	94
Uses of bromine.....	94
Recovery of calcium chloride.....	95
Ohio and West Virginia.....	95
Michigan.....	96
Vacuum-pan process.....	97
History.....	97
Production centers.....	99
Character of product.....	100
Principle of vacuum-pan process.....	101
Construction of apparatus.....	102
Details of operation.....	104
Manistee evaporator.....	104
Other types of evaporators.....	106
Lillie evaporator.....	106
Brecht salting evaporator.....	108
Evaporator shell.....	108
Heating chamber.....	108
Salt filter.....	109
Craney vacuum pan.....	109
Oscar Krenz pan.....	109
Swenson evaporator.....	109
Operation.....	110
Sanborn evaporator.....	111
Construction.....	111
Operation.....	111
Wheeler evaporators.....	111
Zaremba crystallizing evaporator.....	113
Construction.....	113
Heating surface.....	113
Circulation.....	115
Salt filter.....	115
Method of operation.....	115
Milling operations.....	117
Combination salt.....	118
Commercial status of processes.....	118

	Page.
Removal of gypsum from brines.....	121
Relative efficiency of processes.....	122
Technology of mining and milling of rock salt.....	124
Situation and development of mines.....	124
Retsof Mining Co., Retsof, N. Y.....	124
Mining.....	124
Milling.....	125
Sterling Salt Co , Halite, N. Y.....	126
Detroit Salt Co., Detroit, Mich.....	126
Mining.....	126
Milling.....	127
Bevis Rock Salt Co , Lyons, Kans.....	128
Method of sinking shaft.....	128
Mining.....	129
Milling.....	130
Equipment.....	130
Royal Salt Co , Kanopolis, Kans.....	131
Mining.....	131
Milling.....	131
Equipment.....	131
Crystal Rock Salt Co., Kanopolis, Kans.....	132
The salt bed.....	132
Method of sinking shaft.....	133
Mining.....	134
Milling.....	134
Equipment.....	134
Commercial grades of Kansas rock salt.....	134
Myles Salt Co , Grande Cote, La.....	135
Avery Salt Mining Co , Petite Anse, La.....	136
Useful tables connected with the salt industry.....	137
Publications on mineral technology.....	142
Index.....	145

ILLUSTRATIONS.

	Page
PLATE I. <i>A</i> , Salt mine of L. Jacobs, 2½ miles northwest of Redmond, Sevier County, Utah; <i>B</i> , Salt mine of Inland Crystal Salt Co., in Sanpete County, Utah.....	30
II. <i>A</i> , Harvesting salt produced by solar evaporation at Syracuse, N. Y.; <i>B</i> , Salt vats with roofs removed, solar evaporation process, Syracuse, N. Y.	40
III. <i>A</i> , View of crystallizing ponds, Leslie Salt Co., San Mateo, Cal.; <i>B</i> , Salt ponds and salt piles at plant of Union Pacific Salt Co., San Francisco Bay, Cal.	44
IV. <i>A</i> , Gravity method of running brine from one pond to another, Oliver Salt Co. plant, Mount Eden, Cal.; <i>B</i> , Salt gardens, Oliver salt plant, Mount Eden, Cal.	44
V. <i>A</i> , Details of salt crystallization in crystallizing pond, Leslie Salt Co., San Mateo, Cal.; <i>B</i> , View of crystallizing ponds at Leslie plant, San Mateo, Cal.	46
VI. <i>A</i> , Slough and windmills at Oliver salt plant, Mount Eden, Cal.; <i>B</i> , Windmill, Oliver salt plant, Mount Eden, Cal.	46
VII. <i>A</i> , Loading salt on small cars to be carried to the plant for refining, at Oliver salt plant, Mount Eden, Cal.; <i>B</i> , Harvesting salt in the harvesting pond of the Long Beach Salt Co., Long Beach, Cal.	48
VIII. Panoramic view showing salt ponds during harvesting process, Long Beach Salt Co., Long Beach, Cal.	48
IX. <i>A</i> , Leslie salt plant, San Mateo, Cal.; <i>B</i> , Method of mechanically lifting salt from the salt ponds at California salt plant, Alvarado, Alameda County, Cal.	50
X. <i>A</i> , Plowing salt in harvesting ponds, preparatory to harvesting the salt; <i>B</i> , Loading salt onto car for shipment to refining plant, Inland Crystal Salt Co., Saltair, near Salt Lake City, Utah; <i>C</i> , Royal salt plant and refuse salt pile, Kanopolis, Ellsworth County, Kans.	52
XI. <i>A</i> , Open-pan room, Western Salt Works, Hutchinson, Kans.; <i>B</i> , Typical country salt plant east of Nephi, Utah.	60
XII. Plan and sectional elevation of automatic salt raker with hydraulic drive.	66
XIII. <i>A</i> , Outside settling tanks, Worcester salt plant, Silver Springs, N. Y.; <i>B</i> , Preheating tanks, Worcester salt plant, Silver Springs, N. Y.	70
XIV. <i>A</i> , Grainers in which salt is lifted by hand, Worcester salt plant, Silver Springs, N. Y.; <i>B</i> , Grainers at Liverpool salt plant, Hartford, W. Va.	70
XV. Thirty-foot pan.	102
XVI. Side elevation of a triple effect vacuum pan.	104
XVII. End elevation of triple-effect vacuum pan.	104
XVIII. Section through quadruple-effect Lilje evaporator.	106

	Page
XIX. Brecht evaporator	108
XX Craney type of vacuum pan	110
XXI Oscar Krenz evaporator	110
XXII Market sizes of salt	118
XXIII <i>A</i> , Rotary cylinder drier used in drying high-grade salt. <i>B</i> Type of screen used at many salt plants in United States	118
XXIV. <i>A</i> , Coarser grades of rock salt produced in Kansas rock-salt mines. <i>B</i> , Finer grades of rock salt produced in Kansas rock-salt mines	130
FIG 1 Plan and sections of pan block	56
2. Preheating tank for brine at base of chimney	69
3 Apparatus for producing and separating bromine without distillation	96
4 Essential parts of vacuum pan	100
5 Section of a single-effect vacuum pan	103
6 Swenson triple-effect evaporator	110
7. Sanborn salt evaporator	112
8 Wheeler salt evaporating pan with continuous elevator	114
9 Flow sheet of milling process, Sterling salt plant Halite, N. Y.	127
10 Section showing method of sinking shaft through water-bearing stratum at Bevis salt plant, Lyons, Kans.	128

PREFACE.

This report on the technology of salt production in the United States is the outcome of studies that have extended over several seasons and is based on work undertaken primarily in connection with the Government's efforts to find deposits of soluble potash salts in the United States. Nearly every active salt plant in the United States has been visited, the source of supply and the methods of extracting the salt from the brine have been studied, and hundreds of samples collected for analysis. The results of the work have been prepared for publication in two parts. One of these is to be published by the United States Geological Survey and relates to (*a*) the geology of salt deposits, (*b*) the theories connected with their origin and formation, (*c*) the chemistry of the salt beds and natural brines, and (*d*) the statistics of salt production in the United States. The part embraced by this report, published by the Bureau of Mines, relates to processes of technology.

Though the literature contains many descriptions of the salt industry in different parts of the United States, few of them treat in detail the technology of salt making. Most of the reports present information on the industry in particular States.

In recent years general reports on salt have been issued in English, but these have related to English and Canadian practice, and United States methods have been passed over with descriptions entirely inadequate to present-day progress. The work of T. M. Chatard, which relates chiefly to the industry in the United States, was written 30 years ago. The character of the machinery, the quality of the labor, and the use of labor-saving devices have undergone profound changes since that report was written. The remarkable development of mechanically-raked grainers and the establishment of the vacuum-pan process illustrate the advancement made. In some of the modern grainer and vacuum-pan plants the salt is not touched by hand from the time that it crystallizes from the brine till it is ready to be wheeled into the cars for shipment to consumers.

The importance of the salt industry needs no comment. The domestic output in the United States in 1915 was 5,352,409 short tons, valued at \$11,747,686. This industry is scattered over 14 States, distributed from coast to coast and from the Great Lakes to the Gulf. Competition has been keen in it, and this, together with the low value of the commodity, prevents its transportation to considerable distances except where local prejudice favors a certain brand. This competition has led to loss.

The general view of the industry, that Mr. Phalen was enabled to obtain from his visits to all the operating plants in the United States

enabled him to draw certain general conclusions with reference to the industry. One of these was the great excess of plant capacity as compared with the domestic requirements. The consensus of opinion seemed to be that much more salt was being produced than could be marketed, estimates of overproduction ranging from 20 to 50 per cent. The facts that large, up-to-date plants were not working at full capacity, that others were working at half time or half capacity, and that others were either temporarily or permanently closed, are significant to those planning to enter the salt business.

The rapid deterioration of the equipment also deserves consideration. The wear and tear on all salt-making machinery is heavy. If a plant is allowed to remain idle for any considerable time it is well nigh ruined. For this reason it may often be cheaper to make salt for a season without profit than to shut down. In figuring costs and basing selling price on them some producers have not provided for the rapid deterioration of plant, and this, together with overproduction, has caused heavy losses among salt manufacturers during the past decade.

Mr. Phalen points out the possibilities of utilizing the residual bittern (mother liquor) from salt making, and especially the recovery of potash and magnesium salts. Along the California coast and on the shores of Great Salt Lake, the mother liquors contain considerable quantities of these salts. As the cost of magnesium salts on the Pacific coast has been high during the war, and as the potash salts for fertilizer have been difficult to procure recently at any price, the value of these mother liquors should be appreciated, and seemingly this fact is beginning to be realized.

The report presents a valuable series of analyses made by W. B. Hicks, of the United States Geological Survey, of representative samples of natural brines. Most of these brines are now worked for salt, bromine, and calcium chloride, but some of them, for example, in northern Ohio and parts of Michigan, have never been used. These brines deserve careful investigation as a possible basis of chemical industries. The report also includes:

1. An outline of the general distribution and character of the salt deposits of the United States, which is inserted because all the readers of the report will probably not have access to the Survey's complementary report.
2. A detailed description of the different methods of salt making—by solar evaporation, direct heat (including the open-pan process), and steam evaporation (including grainer and vacuum-pan practice).
3. An outline of the manufacture of bromine from natural brines, and a description of the preparation of calcium chloride.

VAN H. MANNING,
Director.

TECHNOLOGY OF SALT MAKING IN THE UNITED STATES.

By W. C. PHALEN.

INTRODUCTION.

During the search for deposits of soluble potash salts in the United States, carried on by the United States Geological Survey, much information was collected on the salt resources and industry of the United States. The more important features of the information thus gathered, compiled, and digested may be classified under five headings, as follows:

1. Geology of the salt deposits of the United States.
2. Theories relating to the origin and formation of salt deposits.
3. Chemical composition of saline materials in the United States, principally rock salt and natural and artificial brines.
4. Statistics of salt production in the United States.
5. Technology of salt production.

The first four items are not discussed in this report, but their treatment will comprise a separate report published by the Geological Survey,^a which will supplement this report, relating to salt-making processes, and will describe comprehensively the salt resources of the United States. Persons desiring a copy of that report should apply to the Director of the United States Geological Survey, Washington, D. C.

In addition to the discussion of processes, this report gives a brief description of the more important sources of salt in the United States. This description has been abstracted from the much lengthier description contained in the report to be published by the Geological Survey.

FIELD WORK DONE.

The field investigation of the sources of salt was made chiefly in 1911 and 1912, but salt-making processes, or technology, was further studied in 1916, with a view to bringing the discussion of that subject up to date.

The field work extended over the western part of New York and included visits to operating plants in Wyoming, Livingston, Genes-

^a Phalen, W. C., Salt resources of the United States: U. S. Geol. Survey Bull. 669. In course of publication.

see, and Tompkins Counties. Every active plant in the lower peninsula of Michigan was visited, including plants in Midland, Saginaw, Bay, and Isabella Counties, where are natural brines containing bromine in commercial quantity, and bromine and other chemicals, including magnesium salts, are now obtained. The process of obtaining bromine, and the possible utilization of these and other natural brines containing bromides, lime, and magnesium salts, is discussed on subsequent pages.

Such natural brines are found at Malden, in the Kanawha Valley, W. Va., and a long Ohio River in the vicinity of Pomeroy, Meigs County, Ohio, and at Mason and Hartford, Mason County, W. Va. They also underlie a large area in northern Ohio, including the region around Akron, Barberton, Wadsworth, Rittman, Cleveland, and Airport Harbor. The brines in northern Ohio have never been worked, and, indeed, great care has to be exercised that they do not get into the salt wells and ruin them by polluting the brine. The different localities mentioned have been visited in connection with this work, and where the brine is being utilized the methods of salt making were studied. Samples were collected for analyses in most places where they could be procured.

The Kansas salt field and the salt-producing localities in Louisiana and Texas were visited.

The field work during 1912 consisted chiefly of visits to salt-producing districts in the far Western States, including the shore of Great Salt Lake and the salt-producing localities south of Salt Lake in Sevier, Sanpete, and Juab Counties, Utah, the solar evaporation plants that were in operation on the east and west sides of San Francisco Bay in Alameda and San Mateo Counties, Cal., and the solar evaporation plants in the southern part of the State, near Long Beach, Los Angeles County, and on San Diego Bay, San Diego County.

ACKNOWLEDGMENTS.

The writer takes this opportunity to thank his many friends in the industry who have so generously contributed both time and information. Specific credit is due his former colleagues in the Geological Survey, Messrs. H. S. Gale, R. K. Bailey, W. B. Hicks, and the late R. B. Dole. Acknowledgments are cordially made to George B. Willcox, president of the Willcox Engineering Co.; S. M. Lillie, Philadelphia, Pa.; A. G. Dawson, of the Manistee Iron Co., Manistee, Mich.; the Zarembo Co., Buffalo, N. Y.; the Swenson Evaporator Co., Chicago, Ill.; the Brecht Co., St. Louis, Mo.; the Bay City Iron Co., Bay City, Mich.; the Sanborn Evaporator Co., New York City; the Wheeler Condenser & Engineering Co., Carteret, N. J.; and the Oscar Krenz Copper & Brass Works, San Francisco, Cal.

MINERALOGY OF SALT.

Common or rock salt is known to mineralogists as halite. It is the chloride of sodium, composed of 39.4 per cent chlorine, which in its free state is a gas, and 60.6 per cent sodium, which in its free state is a metal. Halite is rather brittle and has a conchoidal fracture. Its hardness is 2.5; its specific gravity ranges from 2.1 to 2.6, that of pure crystals being 2.135; its index of refraction is 1.5442: and it is highly diathermous. It seldom occurs perfectly pure, but is mixed with a variety of other saline minerals—such as gypsum, anhydrite and, in Germany, carnallite, kieserite, and polyhalite—or is associated with shale and sandstone.

Halite crystals are isometric and usually form cubes, commonly distorted and in cavernous shapes termed hopper-shaped crystals. Halite also occurs massive with a granular to compact structure. Masses with perfect cubical cleavage are common, as also those with fibrous texture which are said to be pseudomorphous after gypsum. Rock salt has a vitreous luster, and when pure is transparent and colorless. The different shades of color are due to impurities which impart yellow, red, brown, blue, and purple hues, and are responsible for the varying degrees of translucency. Salt is readily soluble in water, and its characteristic taste is known to all.

THE USES OF SALT.

Salt is largely used for culinary purposes and also in the meat-packing, fish-curing, dairying, and other industries to prevent deterioration. It is also used extensively for refrigerating purposes, a familiar example being the making of ice cream. The treatment of gold and silver ores by chlorination also consumes some salt. In the form of brine it is largely used in the chemical industries in the preparation of soda ash, caustic soda, and various other chemicals containing a sodium base.

Besides the uses given above, other miscellaneous uses are: To form a glaze on pottery; in enameling and pipe works; salting cattle; curing hides; making pickles; and clearing oleomargarine. Recent experiments have indicated that it may prove of value in aiding the recovery of potash salts as a by-product in the Portland cement industry.

TYPES OF OCCURRENCE.

Salt is widely distributed and in many places forms beds of sufficient size to constitute true rock masses. It is also found in solution in salt springs, in the water of the ocean, and in inland salt lakes or seas, as in the Great Salt Lake and the Dead Sea. Interstratified deposits of rock salt have been formed by the gradual evaporation

of bodies of sea water cut off from the main ocean. The salt water of inland salt lakes or seas, like the Great Salt Lake and the Dead Sea, has been concentrated by evaporation. In such inclosed bodies of salt water the minerals in solution crystallize out in the order in which the solution becomes saturated with the various solid salts. This order depends partly on the relative quantities of the various constituents originally in the water and partly on the solubility of the precipitated salts.

Rock salt is of such general occurrence that a list of the localities where it is found would include almost every civilized country. In the United States there are extensive and valuable deposits of salt in central and western New York, in Pennsylvania, Ohio, Michigan, Virginia, Kansas, Louisiana, Texas, Nevada, Utah, Arizona, New Mexico, California, Idaho, Wyoming, and probably in several other States. Salt springs and wells abound in the neighborhood of the salt deposits, and these, as well as the waters of salt lakes and sea water, constitute the sources of the commercial product.

SALT DEPOSITS OF THE UNITED STATES.

GENERAL DISTRIBUTION AND CHARACTER.

Of the useful minerals found in the United States perhaps none occurs in seemingly greater abundance or is more widely distributed than common salt. The various modes of occurrence include crystalline layers interbedded with other sediments, which may have been chemically precipitated, as gypsum, or may be ordinary clastic sediments, as sandstone and shale; in beds of dry or nearly dry lakes, marshes, or alkali flats; or in the form of dissolved salt, in natural brines or bitterns issuing from salt springs or accumulated in salt lakes or ponds.

In the eastern part of the United States salt does not lie at the surface of the ground, as in many parts of the West. In New York, western Pennsylvania, Michigan, Ohio, Kansas, Virginia, Louisiana, New Mexico, and eastern and northwestern Texas salt forms rock deposits well below the surface, where it is protected from the solvent action of rain and ground water by a thick mantle of impervious beds. In the far-western States, Idaho, Wyoming, west Texas, New Mexico, Arizona, Nevada, and California, many important saline deposits are exposed at the surface because the climate is arid. Thus the United States may be divided into east and west parts with reference to its salt resources, the division being not only geographic, but climatic.

In the Western States are many localities having large and important salt deposits, the presence of salt being attested by many place names. The greater part of Nevada, large parts of Utah and California, and small parts of Oregon, Idaho, and Wyoming are included within the Great Basin Region, so-called. In this region lie the drainage basins of the former Lake Lahontan and Lake Bonneville. These basins have been studied by Gilbert^a and Russell.^b The conclusions of these two men regarding the salines deposited from the waters of these lakes, their accumulation, disappearance from the surface, and the possibility of finding them below the surface are discussed in the report that will be published by the United States Geological Survey.

^a Gilbert, G. K., Lake Bonneville U. S. Geol. Survey Mon. 1, 1890, 438 pp

^b Russell, I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 1885, 288 pp.

NEW YORK.

EARLY DEVELOPMENTS.

Rock salt was discovered in New York in 1865 at the village of Vincent, in western Ontario County. The importance of the find was not fully appreciated until after rock-salt beds had been found in other places. Early in 1878 one of several test wells sunk in western New York in a search for oil encountered a bed of rock salt 70 feet thick at a depth of 1,279 feet, a mile south of Wyoming. This well became known as the "pioneer well." Three years later, in March, 1881, works with the small capacity of 40 barrels a day were erected, and salt was first made from artificial brine. Shortly after this discovery successful exploration took place at Le Roy, north of Wyoming, and salt was first made at Le Roy in the spring of 1884.

In the meantime progress was made in another part of the State. In August, 1881, a company of citizens of Warsaw began to sink a well near the Buffalo, Rochester & Pittsburg Railroad, in the northern part of the town, and in October of that year found a bed of salt and shale 111 feet thick at a depth of 1,520 feet. Eighty feet of the bed proved to be salt. An abundant supply of water from which artificial brines could be made was also encountered. It was soon shown that the artificial brine was fully saturated, of great purity, and practically unlimited in quantity. The development of the salt industry in this general locality in the Oatka Valley was very rapid in 1883. In that year salt was found in the Genesee Valley by a well near the shaft of the Rcts of Salt Mines, 10 miles directly east of the Pioneer well in the Oatka Valley. In September, 1885, a shaft 9 by 12 feet reached rock salt near Greigsville, at a depth of 996 feet. Many wells and a few other shafts were put down in the Genesee Valley during the following years.

The discovery of rock salt at Wyoming revived interest in the search for the bed that geologists had asserted must exist in the higher land south of Syracuse, and in 1881 a well was sunk at Jamesville, 7 miles southeast of the head of Onondaga Lake. In 1882 another well was sunk at Cedarvale, $7\frac{1}{2}$ miles southwest of the Indian land reservation. Rock salt was not found in either of these wells. In 1884 two wells were put down near Onondaga Salt Springs, one by private parties and the other by the State. No rock salt was found in the Salina formation by either of these wells. In 1885 a test well sunk at Ithaca to a depth of 3,185 feet found salt, and a careful record was made of it. The stratigraphy of the Ithaca well has been described by Prosser.^a In 1886 a well at Morrisville, Madison County, struck rock salt. This well marks the most easterly point at which rock salt has

^a Prosser, C. S., The thickness of the Devonian and Silurian rocks of western central New York, Am. Geologist, vol 6, October, 1890, pp 202-203.

been found in the State and the most northerly point east of Genesee River, with possibly a single exception.

In 1888 the Solvay Process Co., of Syracuse, in searching for a larger and cheaper supply of brine for its great soda-ash plant at Syracuse, began a well in the south end of the valley of Onondaga Creek in the town of Tully, 17 miles south of Syracuse. This well was abandoned after it had passed through 400 feet of glacial drift, but another well a quarter of a mile farther east found at a depth of 1,216 feet a bed of rock salt 45 feet thick. In 1889, 10 new wells were put down; in 1890, 10 more; and in 1891, 9 more, all on the east side of the valley. In 1893 and 1896, 11 additional wells were drilled on the opposite side of the valley, making a total of 41 wells drilled to the salt bed there by this company. Forty of these wells are connected by iron pipes with Tully Lakes. The lake water flows by gravity to the salt and becomes saturated with it. This brine formerly flowed through other pipes into a large main that conveyed it to Syracuse, where the works are 360 feet lower than the mouth of the lowest well, but owing to the loss by this method the wells are now pumped.

In 1891 a well was sunk to the salt bed at Ludlowville, Tompkins County, and a second well was put down in 1892. In 1893 another well was drilled at Ithaca, north of the well put down in 1885. In 1893, 1894, and 1896 wells were sunk at Watkins, Schuyler County, and salt is now being made at that place. A shaft is reported to have been begun on the shore of Lake Cayuga south of Ludlowville in 1916.

RELATIVE IMPORTANCE OF NEW YORK FIELD.

During the past few years New York has ranked second among the States in both quantity and value of salt produced. The industry includes both the mining of rock salt and the evaporation of brine by the solar, open-pan, gramer, and vacuum-pan processes.

POSITION OF FIELD.

The salt field in New York is distinct from that in the near-by State of Ohio, but is related to the deposits in the Province of Ontario, Canada. The salt-bearing Salina formation, outcropping in a belt approximately 12 miles wide at Niagara River, extends eastward across the central tier of counties in New York to a little south of Oneida Lake. The outcrop then turns southeast, narrowing gradually, and terminates in the vicinity of Schoharie River, Schoharie County. Its greatest width, about 20 miles, is at the foot of Cayuga and Seneca lakes. Salt making is confined to the region south of this outcropping belt, that is, in the direction of the dip of the beds, because the salt is leached from outcropping beds in this region of abundant

rainfall. A map presented in Bulletin 669^a of the United States Geological Survey showing the outcrop of the Salina formation brings out these facts and shows the places in the State where salt has been found in wells and shafts.

EXTENT OF DEPOSITS.

The area known to be underlain with rock salt comprises a corner of Genesee County south of LeRoy, the eastern half of Wyoming County, nearly the whole of Livingston County, and the part of Ontario County west of Canandaigua Lake and chiefly south of the New York Central Railroad. Late reports indicate that to the west, in Erie County, rock salt has been found at Eden Valley, Springville, Perry, and Gowanda,^b and in a gas well between Cattaraugus and Gowanda,^c in Cattaraugus County.

East of Canandaigua Lake the borings at Dundee, Watkins, Ithaca, Ludlowville, and Tully all reached the rock-salt beds. The area underlain by rock salt west of Canandaigua Lake is computed by Bishop^d to comprise 1,100 square miles. In view of discoveries made since Bishop's report, his estimate is probably far too low. The area underlain by salt east of Canandaigua Lake must be fully as large as that to the west, if not larger. The northern limit can be assigned only approximately, owing to the rock salt being dissolved near the surface. The southern limit is not known and may never be accurately determined, as the thickness of the cover of Salina formation increases in that direction, but the salt is known to extend at least as far south as the vicinity of Pittsburgh, Pa. The persistence of the salt to the south in New York, however, is indicated by the wells at Ithaca, which reach the salt at a depth of 2,200 feet, and by test borings in northern Cattaraugus and Allegany Counties, which encountered salt at over 3,000 feet. The boring at Canaseraga, Allegany County, penetrated 75 feet of rock salt, beginning at a depth of 3,050 feet.^e

The northern limit, as shown by the outcropping Salina strata, is approximately defined by a line drawn from a point south of Oneida Lake westward to Buffalo. South of this line, the deposits lie progressively deeper in accordance with the dip of the strata, which ranges from 40 to 50 feet per mile. The most eastern point at which salt has been found is Morrisville, Madison County. Between this and Lake Erie salt has been found in almost all of the central tier of counties.

^a Phalen, W. C., Salt resources of the United States U. S. Geol. Survey Bull. 669. In course of publication.

^b Newland, D. H., Mining and quarry industry: New York State Museum Bull. 166, August, 1913, p. 57.

^c Newland, D. H., Mining and quarry industry. New York State Museum Bull. 174, December, 1914, p. 66.

^d Bishop, I. P., Report of the New York State Geologist, vol. 5, 1885, p. 34.

MICHIGAN.

RELATIVE IMPORTANCE OF MICHIGAN SALT INDUSTRY.

During the past few years Michigan has ranked first among the States in both quantity and value of salt produced. Salt in Michigan is obtained from two distinct sources—rock salt and natural brine—and is produced by the open-pan, grainer, and vacuum-pan methods of evaporation. The industry based on rock salt is of much greater importance than that based on natural brine.

POSITION OF SALT FIELDS.

Salt is made in three distinct parts of the State. The producing districts are situated (1) in the southeastern part of the State along Detroit and St. Clair Rivers, (2) in approximately the central part of the Lower Peninsula, especially in the Saginaw Valley, and (3) along the western coast of the Lower Peninsula.

DEPTH TO SALT BEDS.

In the southeastern part of Michigan and to the north along St. Clair River a great many wells have been sunk to the salt beds. Records of these wells are given in United States Geological Survey Bulletin 669.^a The depths to the salt beds are shown in the accompanying table

Depths to salt beds in eastern Michigan

Location	Depth in feet.
Marine City, well No. 1.....	1, 604-1, 637
Marine City, well No. 2 (first bed).....	1, 634-1, 735+
Marine City, well No. 3.....	{ 1, 622-1, 637 1, 642-1, 662 1, 672-1, 737
Marine City, well No. 4.....	{ 1, 570-1, 590 1, 600-1, 630
Marine City, 2½ miles north of, well No. 6.....	1, 600
Marine City, probably west of, well No. 7.....	{ 1, 620-1, 650 1, 675-1, 775
Petrolia, Ontario, 18 miles from Port Huron (in Monroe group) 1, 199-1, 251	
Port Huron, well No. 12 (Monroe group and Salina formation).....	Just above 1, 600 At 1, 600 Above and below 1, 700
Port Lambton, Ontario, 5 miles northeast of Algonac.....	1, 710-1, 720
Royal Oak, well No. 2.....	{ Highest, 1, 543-1, 640 Lowest, 2, 315-2, 475
St. Clair.....	1, 630-1, 660
St. Clair, 5 miles below.....	1, 500
St. Clair, one-half mile east of (in the Monroe group).....	1, 620-1, 650
Wyandotte (bands of salt).....	730-1, 235

^a Phalen, W. C., Salt resources of the United States. U. S. Geol. Survey Bull. 669. In course of publication.

No rock salt occurs in the southwestern part of the State, but it is found to the north, at Ludington and Manistee. At Frankfort, still farther to the north, in Benzie County, wells through the Salina, the salt-bearing formation, did not strike salt, nor even a strong brine. It is likely that Frankfort is just outside the borders of the ancient sea in which the salt was deposited. Likewise the St. Ignace and Cheboygan wells show no salt. The following log shows the beds that a typical well penetrates at Ludington.

Log of salt well put down by J. S. Stearns, at Ludington, Mason County, Mich.^a

[Ten-inch casing, 204 feet, water (53° F.) at about 300 feet, 8-inch casing to rock]

	Material	Thickness, feet	Depth, feet
Pleistocene			
Sand.....		198	-----
Clay, pink, calcareous.....		68	266
Gravel.....		94	360
Clay, pink, calcareous.....		155	515
Gravel.....		61	576
Limestone, with 15 feet of porous granular limestone and salt water 35 feet below the casing.....		74	650
Coldwater			
Shale, blue.....		550	1,200
Antrim			
Shale, black.....		200	1,400
Traverse group			
Limestone, brown.....		25	1,425
Shale, blue.....		35	1,460
Limestone, brown, oily, with hydrogen sulphide.....		40	1,500
Limestone, pure (Dundee?).....		250	1,750
Dolomite, brown, sandy.....		160	1,910
Shale, calcareous.....		90	2,000
Monroe group			
Dolomite.....		25	2,025
Limestone.....		25	2,050
Dolomite.....		25	2,075
Sandstone (Sylvania?).....		100	2,175
Dolomite, sandy, and anhydrite.....		121	2,296
Salt.....		8	2,304

At Manistee are a number of wells 300 to 400 feet shallower than the Stearns well. The depths to salt are shown by some of the records of the Ludington and Manistee wells, as follows

Depths to salt at Ludington and Manistee, Mich.

	Location	Depth to salt, feet
Ludington, well No. 1.....		2,195
Ludington, 1 mile south of.....		2,242-2,260
Ludington, well No. 3.....		1,965-2,001
Manistee, well No. 1.....		{ 1,978-1,985 1,988-2,012
Manistee, well No. 2.....		{ 1,900-1,904 1,912-1,942
Manistee, well No. 3.....		1,988
Stronach.....		1,930-1,964

^a Lane, A. C., Notes on the geological section of Michigan. Michigan Geol. Survey Tenth Ann. Rept. of 1908, 1909, pp. 91-105.

Another area which contains rock salt in some quantity, but has not yet been developed, is about Alpena, in the northeastern part of the Lower Peninsula, on the shores of Thunder Bay, an arm of Lake Huron. Here five beds of salt, with streaks of gypsum and anhydrite, are known, their aggregate thickness being about 300 feet.

OHIO.

RELATIVE IMPORTANCE OF OHIO SALT INDUSTRY.

Ohio has ranked third among the States in recent years in both the quantity and the value of the salt produced. Both salt beds and natural brines are utilized and the product is made by the common processes of evaporation, the grainer and vacuum-pan processes. No rock salt is mined. Considerable brine obtained from beds of rock salt is utilized in the manufacture of soda. Bromine and calcium chloride are also obtained from the natural brines along the Ohio River, and reports indicate that an increase in chemical industries may soon be expected there.

POSITION OF FIELDS.

Ohio salt at present comes from two distinct districts, one in the northeastern and the other in the southeastern part of the State. The southeastern district at present is included entirely within Meigs County and is coextensive with that in West Virginia on the opposite side of Ohio River. The northeastern district comprises Cuyahoga, Medina, Summit, Wayne, and Lake Counties.

SALT DEPOSITS IN NORTHEASTERN OHIO.

Though the salt-producing area in northeastern Ohio is large, salt production thus far has been restricted to Cuyahoga, Summit, Medina, Lake, and Wayne Counties. Salt is not produced as such in Lake County, the brines produced by the Diamond Alkali Co., at Fairport Harbor, being made into other sodium compounds. That the salt beds extend farther east than the producing wells is shown by the following record of the Hadsell well near Cortland, Trumbull County:^a

^a Bownocker, J. A., Salt deposits and the salt industry in Ohio. Ohio Geol. Survey, ser. 4, Bull. 8, 1906, p. 42, Ohio Geol. Survey Econ. Geol. Bull. 8, vol. 9, 1906, pp. 9-42.

Log of Hudson well, near Cortland, Trumbull County, Ohio.

Material	Thickness, feet.	Depth, feet.
Drift	40	—
Shale	60	100
Berea grit	160	260
Shales, Bedford and Ohio	2,386	2,656
Limestones, Cincinnatian and Monroe	583	3,239
Salina formation		
Rock salt	12	3,251
Limestone	5	3,256
Rock salt	2	3,258
Limestone	3	3,261
Rock salt	10	3,271
Limestone	49	3,320
Rock salt	29	3,349
Limestone	10	3,359
Rock salt	52	3,411
Shale, white	18	3,429
Limestone	36	3,465
Rock salt	10	3,475
Limestone	50	3,525
Shale, white	15	3,540
Rock salt	30	3,570
Limestone	10	3,580
Rock salt	3	3,583
Shale, white	90	3,673
Limestone	5	3,678
Shale, blue	32	3,710

This record shows 148 feet of rock salt. If the alternating strata of limestone are similar to those farther west in having many large holes filled with salt, then the total quantity is much in excess of 148 feet. The record shows that the salt strata extend to the eastern line of the State. Although the data from well records in New York do not warrant the statement that the salt beds of New York are coextensive with those of Ohio, the presumption that this is so is strong, as comparatively recent records have shown the existence of rock salt in Erie and Cattaraugus Counties, in localities where it was formerly considered not present. The southern limit of the salt deposits has not been determined, because the strata dip south and east, and the salt lies so deep that it has not been reached by the drill. Westward, also, the limit has not been determined, but can not extend as far as Sandusky, according to the following record obtained near that place, although too much weight must not be attached to the evidence of a single well.^a

^a Orton, Edward, Report of the geological survey of Ohio, petroleum and natural gas. Ohio Geol Survey, vol. 6, 1888, p 195

Log of well, Sandusky, Erie County, Ohio

Material.	Thickness, feet	Depth, feet
Drift.....	10	.....
Limestone, Corniferous.....	100	110
Limestone, Monroe and Niagara.....	970	1,080
Shale, Niagara and Clinton formations	105	1,185
Shale, Medina.....	175	1,360
Shale and limestone, Cincinnati.....	500	1,860
Shale, Utica.....	310	2,170
Shale, not recorded.....	40	2,210
Limestone, Trenton, at.....	.....	2,210

Considering the area beneath which salt is known to exist, and the number and thickness of the salt beds, the conclusion seems warranted that northeastern Ohio contains enough salt to last an indefinite time at the present rate of consumption.

BRINE HORIZON IN SOUTHEASTERN OHIO.

The salt industry in southeastern Ohio centers at Pomeroy, Meigs County, where a natural brine is worked for bromine and calcium chloride, as well as salt. The depths of the wells obtaining brine have increased greatly. At first the wells were shallow, being reported as about 300 feet deep and as reaching the horizon of the first Cow Run sand, an important source of petroleum in Washington and Morgan Counties. Later the wells were deepened to get a larger supply of brine. When this proved inadequate the wells were again deepened.

The following skeleton record of a well belonging to the Buckeye Salt Co. is interesting. The well head is 25 feet below the Pomeroy or No. 8 coal

Log of well near Pomeroy, Meigs County, Ohio a

Material	Thickness, feet.	Depth, feet
Conductor.....	58	.....
Shale.....	492	550
Sand, white and gray.....	320	870
Sand, white, and slate.....	90	960
Big salt sand.....	170	1,130
Sand and white shale.....	365	1,495
Strata unrecorded.....	50	1,545
Berea grit.....	25	1,570
Strata unrecorded.....	20	1,590

^a Brines were struck at 320 feet, density 6° B., at 710 feet, density 9° B., at 980 feet, density 9° B., and at 1,550 feet, density 16° B.

Another record furnished by the Liverpool Salt & Coal Co. is as follows:

Log of well at Hurlford, Mason County, W. Va.

Material ^a	Thickness, feet	Depth, feet
Surface to "Horseneck".....	300	.....
"Horseneck" (containing oil and gas).....	50	350
Chiefly shale.....	110	460
First Cow Run sand (much water, no oil).....	40	500
Shale, etc.....	250	750
Second Cow Run sand.....	40	790
Shale, etc.....	210	1,000
First salt sand.....	50	1,050
Shale.....	55	1,105
Second salt sand.....	60	1,165

As soon as the second salt sand was reached the brine rose in the well to a distance of 600 feet from the surface. In all, the well was drilled to a depth of 1,359 $\frac{1}{2}$ feet, but soon partly filled. The well was to go to the Berea, but the volume of water would have required another line of casing. A very small coal seam was reported in the record, but its exact position was not given.

CHARACTER OF BRINE.

As stated in the table on page 13, the brine in the Berea was much denser than that in the overlying rocks. The quantity, however, was small, and the well is pumped from the horizon of the Big Salt sand (Pottsville), depths 1,105 to 1,165 feet in the record given above. The company has five wells, the depths varying from 1,089 to 1,590 feet, the latter penetrating the Berea. The Excelsior Co. has four wells, whose depths range from 1,100 to 1,200 feet. Wells drilled farther east go deeper, because the beds dip in that direction.

When drilling first began here the water is said to have risen nearly to the well heads and to have overflowed from some wells. As pumping progressed the reservoirs of brine were lowered, and the tubing was extended deeper into the wells.

For many years the Excelsior works have pumped from the 750-foot level. The brine is said to rise slightly when wells in neighboring plants are not in action. The density of the brine increases in the direction of the dip of the rocks—that is, to the southeast—as is shown in the following table.

Increase of density with depth of natural brine, Pomeroy, Ohio

	Density of brine, °B.	Temperature of brine, °F.
Pomeroy Salt Works, west end of Pomeroy.....	8	61 5
Excelsior Salt Co., east end of Pomeroy.....	8 5	63
Syracuse Salt, Bromine & Calcium Works (not now operating).....	10 5	62 5

^a The names of the sands are those applied by the driller

According to Bownocker,^a the variation in density is due to the heavier brines seeking the lower level. The variations in temperature result in part from the different conditions under which the measurements were made. The variation is also due in part to the wells to the southeast being deeper.

The quantity of brine that has been taken from these rocks is enormous, much more than the rocks could at any one time contain, and the excess has doubtless come from surrounding territory. The brine-bearing strata dip toward Pomeroy from the northwest. As the brine has been pumped from the wells, the supply has been renewed from the rocks lying at a higher level.

WEST VIRGINIA.

POSITION OF SALT FIELDS.

West Virginia is an important producer of salt from natural brines, part of which is from sandstones in the Carboniferous. These brines are also an important source of bromine and calcium chloride.

The natural brines now utilized underlie the regions along Ohio and Kanawha Rivers. The Ohio River field is coextensive with that in Ohio, Mason and Hartford, in Mason County, being the centers of the industry in this part of the State. Malden, 6 miles above Charleston, is the site of the salt, bromine, and calcium chloride industry on the Kanawha River.

The Ohio River area in West Virginia is geologically a part of the Pomeroy district of Ohio. Mason, one of the centers of the salt industry in West Virginia, is situated nearly opposite Pomeroy, and Hartford is a short distance farther up the river. The geologic occurrence of the brines at Pomeroy, Ohio, has already been discussed. (See pp. 13 and 14.)^b

KANAWHA RIVER AREA.

The record of a deep well drilled for gas on the Cool Spring Branch of Burning Springs Hollow, 2 or 3 miles from Malden, throws some light on the geological horizon from which brines are obtained on the Kanawha River near Charleston. The horizon of the mouth of the well is thought to be far from the surface at the wells near Malden. According to White,^c the Salt Sand in this record is 837 feet thick, and yields the brine that contains the salt and bromine obtained in the plant at Malden. The term "Salt Sand," as used by White, appears to be equivalent to Pottsville group.

^a Bownocker, J. A., work quoted, p. 26.

^b See also Phalen, W. C., Salt resources of the United States U. S. Geol. Survey Bull. 669. In course of publication.

^c White, I. C., Petroleum and natural gas pressure levels West Virginia Geol. Survey, vol. 1c, 1904, p. 272.

PENNSYLVANIA.

SITUATION OF SALT FIELDS.

Salt, bromine, and calcium chloride from natural brines have been obtained in recent years on the North Side, in Pittsburgh, Pa. Early in 1914, however, the industry was discontinued because the brines became so dilute that their treatment was unprofitable.

At the salt plant four wells were in operation. One well, one of the deepest in Pennsylvania, reached a depth of 4,089.5 feet, and penetrated nearly 4,000 feet of beds that do not outcrop near by. Brine was obtained in this well at a depth of 1,405 feet, from a sand designated in the record as "salt sand." This sand is probably in the Pocono formation, of Mississippian age, and possibly is the equivalent of the Berea sandstone.^a The record of the well is as follows:

Log of the John A. Beck No. 4 gas well at Pittsburgh, Allegheny County, Pa.

Material	Thickness, feet	Depth, feet
Ashes and clay	20	20
Gravel	49	69
Slate (water at 95 feet)	30	99
Sand (drive pipe, 73 feet)	40	139
Slate	81	220
Sand	50	270
Slate	15	285
Lime	5	290
Slate	89	379
Coal	7	386
Slate (10-inch casing, 390 feet)	50	436
Lime	30	466
Slate	10	476
Sand	30	506
Slate	10	516
Lime	15	531
Sand	45	576
Slate	124	700
Sand	10	710
Slate (8½-inch casing, 840 feet)	35	745
Sand, Big Injun	319	1,064
Slate	10	1,074
Sand	70	1,144
Slate	15	1,159
Sand	20	1,179
Slate	5	1,184
Sand	20	1,204
Slate and shell	46	1,395
Salt sand (salt water at 1,405 feet)	95	1,490
Sand	30	1,520
Slate	10	1,530

^a Munn, M. J., Oil and gas fields of the Carnegie quadrangle, Pennsylvania. U. S. Geol. Survey Bull. 456, 1911, pp. 11-12.

Material	Thickness, feet.	Depth, feet
Sand.....	115	1,645
Slate (68-inch casing, 1,645 feet).....	5	1,650
Sand (little gas at 1,655 feet).....	10	1,660
Slate.....	50	1,710
Sand.....	30	1,740
Slate.....	20	1,760
Sand (Gordon Stay?).....	10	1,780
Slate.....	5	1,785
Red rock.....	5	1,790
Sand (Gordon?)	30	1,820
Slate.....	35	1,855
Sand	10	1,865
Slate and shell.....	60	1,925
Sand, fith.....	23	1,948
Slate and shell.....	82	2,030
Sand.....	10	2,040
Slate and shell.....	310	2,350
Sand	30	2,380
Slate.....	110	2,490
Sand.....	40	2,530
Slate.....	35	2,565
Sand.....	40	2,605
Slate.....	195	2,800
Sand.....	20	2,820
Slate.....	580	3,400
Sand.....	40	3,440
Slate and shell.....	560	4,000
Sand.....	40	4,040
Slate and shell.....	49 5	4,089 5

Two other records of deep wells in western Pennsylvania show that the salt-bearing formation of western New York, the Salina, extends into western Pennsylvania. One of these wells, known as the Derrick City or Bradford City well, was drilled by the Bradford Deep Well Co., 4 miles northeast of Bradford, McKean County, Pa., in 1912 and 1913. This well reached a depth of 5,820 feet, and struck four beds of salt, ranging in thickness from 10 to 47 feet. The top of the highest salt bed was at a depth of 4,490 feet, and the base of the lowest was at 4,713 feet, the salt-bearing beds thus extending through a total thickness of 223 feet.

The other deep well, known as the McDonald well, is situated about 4 miles northwest of McDonald, Washington County, Pa., some 14 miles southwest of Pittsburgh. In this well, salt water was encountered at approximately 6,825 feet, and rock salt was found in the 350-foot interval between 6,825 feet and 7,175 feet.

VIRGINIA.

The only economically important deposits of salt in Virginia are in the southwestern part of the State. These, with the gypsum deposits, underlie for 20 miles the valley of the north fork of the Holston River, and have been developed rather extensively in Smyth and Washington Counties. Two gypsum plants and one alkali works in which salt is utilized are now in operation.

The salt and gypsum deposits, according to Eckel,^a lie within the lower member of the Greenbrier (Newman) limestone, which is 600 to 1,000 feet thick, and consists of shaly limestones with one or more beds of gypsum underlain by blue shales, or "slates," that are in turn underlain by shales or shaly limestones containing thick beds of rock salt. Thus lower member of the Newman limestone seems to be local, as it has been recorded only in this region.

None of the earlier wells drilled on the Robertson property southwest of Saltville show an appreciable quantity of salt, perhaps because there was no salt where the drilling was done, or because drilling stopped before reaching the salt. Although no records of the wells are obtainable, salt was reached at a depth of 800 feet, and it is said that the aggregate thickness of the rock-salt beds penetrated is 175 feet.

In a description of the area Stose^b divides the Mississippian rocks there into three formations as follows: (1) An upper limestone called the Newman limestone, with a thickness of about 3,325 feet; (2) the Maccrady formation of shales, sandstones, and limestones, with a thickness of 1,025 feet, more or less; and (3) the Price sandstone, with a thickness of 327 to 424 feet. The most striking fact is that the gypsum and salt deposits of the district have been found in quantity only in the shales of the Maccrady formation along the Saltville fault.

Stose differs from Eckel in regard to the origin of the salt and gypsum deposits, believing them to be largely secondary and not primary, and to have been derived from calcareous-argillaceous sediments originally containing disseminated gypsum and salt which precipitated in a partly inclosed arm of the sea. The disseminated salt and gypsum was subsequently concentrated in the same formation by ground waters circulating along the fault zone between the Carboniferous and Cambrian rocks.

^a Eckel, E. C., Salt and gypsum deposits of southwestern Virginia: U. S. Geol. Survey Bull. 213, 1903, pp. 408-416.

^b Stose, G. W., Geology of the salt and gypsum deposits of southwestern Virginia: U. S. Geol. Survey Bull. 530, 1912, pp. 232-255.

Following is a generalized record of a typical well on the property of the Mathieson Co. at Saltville, Smyth County:^a

Generalized record of typical well of Mathieson Co., Saltville, Smyth County, Va.

Material	Thickness, feet	Depth, feet
Limestone and shale.....	26	26
Shale and gypsum.....	195	221
Mostly shale with gypsum and some rock salt.....	359	580
Mostly limestone with shale, gypsum, and rock salt.....	215	795
Mostly shale with gypsum and rock salt.....	100	895
Mostly rock salt with little shale.....	197	1,092

KANSAS.

RELATIVE IMPORTANCE OF KANSAS SALT INDUSTRY.

In 1915, Kansas ranked fourth among the States, both in the quantity and the value of the salt made that year. The State produces much rock salt and also evaporated salt made by the open-pan, grainer, and vacuum-pan processes.

POSITION AND EXTENT OF SALT DEPOSITS.

In a small part of north, middle, and south-central Kansas salt occurs in salt marshes as brine. During the dry season this brine evaporates, leaving rock salt in the so-called salt plains. Salt from this source is not at present utilized, so far as known.

The rock salt now worked at Lyons and Kanopolis, and supplying the brines at Ellsworth, Hutchinson, Sterling, Lyons, Anthony, and other places, lies well below the surface. Salt in the form of brine also occurs in certain beds of the Permian and Pennsylvanian ("Coal measures") in the eastern part of the State. Rock salt is known to exist below the surface in the south-central part of Kansas, including all of Rice and Kingman Counties, nearly all of Reno County, and parts of Saline, Ellsworth, Barton, McPherson, Stafford, Harvey, Pratt, Sedgwick, Barber, Harper, and Sumner Counties.

The rock-salt beds of Kansas lie in rocks of Permian age, that form the Marion formation. These thin to the eastward beyond Wellington and Little River and die out, possibly without coming near the surface. The salt springs at Geuda Springs, Sumner County, are thought to have their origin in these salt beds. How far the salt and associated beds extend westward is not known. To the north and south the beds are fairly well known through drill records, from Kanopolis, Ellsworth County, on the north, to Anthony, Harper County, on the south; that is, nearly to the Kansas-Oklahoma State line. The beds thin northward. At Anthony they are 404 feet

^a Stose, G. W., work quoted, p. 252.

thick (depth 946 to 1,350 feet); at Kingman, 415 feet thick (depth 665 to 1,080 feet), at Hutchinson, 380 feet thick (depth 430 to 810 feet); at Lyons they are 275 feet thick (depth 793 to 1,068 feet); and at Kanopolis about 250 feet thick (depth 630 to 880 feet). If they maintained this rate of thinning from Hutchinson northward, the salt-bearing beds would disappear before reaching the Nebraska line. Where more than one record is obtainable at a given place, for example, Hutchinson, the exact thickness of the salt-bearing beds and the depth to the topmost bed vary somewhat and may vary considerably from the figures given. The records of the wells at Kanopolis, Lyons, Hutchinson, Kingman, and Anthony contain no reference to appreciable quantities of gypsum below the salt.

LOUISIANA.

RELATIVE IMPORTANCE OF LOUISIANA SALT PRODUCTION.

Louisiana, in 1915, ranked fifth in the quantity but sixth in the value of the salt produced. The output in this State is rock salt.

SITUATION OF DEPOSITS.

Although salt occurs in two distinct parts of the State, namely, the north central and northern part, and the southern part, the more important known deposits and those worked at present are in the southern part of the State close to the Gulf coast.

SALINES OF NORTHERN LOUISIANA.

In the northern part of Louisiana, in the valley of Sabine River, salt springs are known at Negreet, about 1.5 miles above the mouth of Bayou Negreet in Sabine Parish, in the SW. $\frac{1}{4}$ sec. 24, T. 5 N., R. 13 W.; at Stone Coal Bluff Saline, in sec. 33, T. 6 N., R. 13 W.; near Many on the road from Marthaville to Many near Rock Springs Church in the NE. $\frac{1}{4}$ sec. 24, T. 8 N., R. 11 W.

In the valley of Red River are situated the following: Bayou Castor Saline, 5 miles north of Rochelle or about 4 miles above the mouth of Dugdemona River; Catahoula Salt Springs, on Catahoula Lake; Browns Saline, 6 miles west of Tullos or 18 miles southeast of Winnfield on Dugdemona River, near Georgetown at Rochelle, Tullos, and Selma; northwest of Winnfield, Winn Parish, at Cedar Bayou Saline and at Coochie Dome.

Important salines, from which much evaporated salt was obtained during the Civil War and earlier, were known as Drake's, Price's, Rayburn's, and King's, after the names of their respective owners or managers. Bistineau Saline, the largest saline in northern Louisiana, was situated in Lake Bistineau, in secs. 25, 26, 35, and 36, T. 18 N., R. 10 W.

A full account of the more important salines of northern Louisiana is given by Veatch.^a

SALINES OF SOUTHERN LOUISIANA.

The most important salt deposits of the State are on the Five Islands, or Salt Islands as they are sometimes called, namely, Petite Anse, Grande Côte, Belle Isle, Côte Blanche, and Côte Carline. On Avery's Island (Petite Anse) and Weeks Island (Grande Côte), rock salt is now being mined on an extensive scale.

Other localities in southern Louisiana where the geologic conditions are similar to those on the Five Islands and where rock salt or salt water, indicating the possible presence of rock salt, has been found in deep drillings, are Anse la Butte, Prairie Mamon, Welsh, Chicot, Vinton, and Hackberry.

Rock salt is mined on Grande Côte (Weeks Island) and Petite Anse (Avery's Island).

GRANDE CÔTE (WEEKS ISLAND).

SITUATION.

Grande Côte is situated on the east shore of Weeks Bay, an eastern lobe of Vermilion Bay, in Iberia Parish, and can be reached by the Cypremort branch, from Baldwin, of the Southern Pacific Railroad. Grande Côte is the largest of the Five Islands, which have been described by Veatch,^b though it is barely 2 miles in diameter.

The geology of the beds at the two localities producing salt is described below in some detail, because the occurrence of the salt and the associated gypsum and sulphur is quite different from that of the salt mined elsewhere in the United States. The description below may be considered typical of deposits in most other parts of the Gulf coastal plain of Louisiana and Texas. Fuller discussions of the geology and hypotheses of origin can be found in Bulletin 669 of the United States Geological Survey.^c

OCCURRENCE OF SALT.

At Weeks Island a great mass of rock salt has formed or is forming beneath the superficial beds of unconsolidated sands, clays, and gravels. The topography is not rugged and there are few outcrops. The uppermost bed on the island is a yellow loamy clay, which is exposed in a few places.

^a Veatch, A. C., The salines of north Louisiana: Louisiana Geol. Survey Rept., pt. 6, 1902, pp. 47-100.

^b Veatch, A. C., The Five Islands: Louisiana Geol. Survey Rept. for 1899, pt. 5, pp. 231-237; Geology and agriculture, Louisiana Geol. Survey, Special Rept. No. 3, 1899, p. 209 et seq.

^c Phalen, W. C., Salt Resources of the United States. U. S. Geol. Survey Bull. 669. In course of publication.

The records of 44 wells in different parts of the island begin in clay that is 40 to 60 feet thick. Below the clay are sands, ferruginous in places, sand containing chert pebbles, and gray sandy clays, tilted at various angles and striking in different directions. The records show gravel and sand layers that are several hundred feet thick in places. The salt is usually, though not everywhere, overlain with a few feet of clay, for some of the wells show layers of lignite just above the salt.

The salt mass of the island comes closest to surface near the mine, slopes abruptly south and west, less abruptly east, and slightly northward. It occupies the west side of the island and appears to extend a little west of the main ridge. Its form is that of an elongated dome with the north-south diameter longer than the other. The upper surface of the salt mass is known to be irregular and to bear little relation to the surface irregularities of the island. The general shape of the salt mass is regarded by Harris^a as having been formed somewhat as it is at present and not to be due mainly to erosion or subterranean solution.

PETITE ANSE (AVERYS ISLAND).

SITUATION

Petite Anse or Averys Island is situated in Iberia Parish about 10 miles south-southwest of New Iberia, in T. 13 S., R. 5 E. and 6 E., Louisiana prime meridian.

OCCURRENCE OF SALT.

Veatch and others have described the geology of Petite Anse in considerable detail.^b According to Harris,^c the details given in the earlier descriptions "are of no serious moment in the interpretation of the geology of this and the other salt islands. All beds here seen are admittedly of Quaternary age; none containing anything that can not be referred to inter or post glacial times."

A brownish-yellow loamy soil forms the greater part of the surface. Exposures of gravel are commoner than on the other islands, but seem to be confined chiefly to the southern end of the island. In the northern part are numerous outcrops of a variegated chocolate-yellow or green jointed clay. A bed of lignite was found at the head of Iron Mine Run Hollow, and vertebrate remains of Pleistocene (according to Veatch) mammalia have been found.

^a Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, pp. 8-9.

^b Veatch, A. C., The Five Islands: Louisiana Geol. Survey Rept. for 1899, pt. 5, pp. 237-253, Geology and agriculture, Special Rept. No. 3, Louisiana Geol. Survey, 1899, pp. 243-248.

^c Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, pp. 14-17.

The records of two wells on the island are given below:

Section of well near sugar house, Petite Anse, La.

Material.	Thickness, feet.	Depth, feet.
Superficial detritus.....	330	.....
Rock salt.....	2,263	2,593
Blue gas sand.....	70	2,663
Salt.....	66	2,729

Section of well at pumping station, Petite Anse, La.

Material ^a	Thickness, feet.	Depth, feet.
Yellowish clay.....	500	.....
Gravel.....	200	700
Grayish sand.....	2,112	2,612

The upper surface of the salt mass is irregular, as on Weeks Island, and in a few places rises slightly above sea level. Consequently the rock salt lies higher than on Grande Cote or at any other point in the State. Brine springs, well known long before rock salt was actually discovered, attest the elevation of the salt.

TEXAS.

SITUATION OF SALT-PRODUCING AREAS.

Salt in Texas in recent years has come chiefly from Palestine, Anderson County, and Grand Saline, Van Zandt County, in the eastern part of the State. Colorado, Mitchell County, in the western part of the State, was formerly a salt-producing center, but only solar salt now comes from there. The industry of large commercial importance is confined chiefly to the manufacture of evaporated salt, but the salt formed naturally by solar evaporation, in the playas of the western and the lagoons of the southwestern part of the State, is used locally.

Rock salt has been found at the following localities in southeastern Texas, all within the area mapped Pleistocene and Recent by Deussen:^b Spindletop, Jefferson County; Sour Lake, Hardin County; High Island, Galveston County; Damon Mound, Brazoria County; and Dayton Hill, Liberty County; and there is a single mention of salt in drilling at Batson, Hardin County.^c According to the drillers, 12 feet of salt were found in a well northeast of the center of the Batson field at a depth of 1,007 feet, or 130 feet above the oil rock. In the absence of other mention of salt in this field, this record can not be accepted without reserve. According to Harris,^d streaks of

^a Gravel bed at about 1,500 feet. No salt or water found by the well.

^b Duessen, A., Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water Supply Paper 335, 1914, Pl. I, see also Fenneman, N. M., Oil fields of the Texas-Louisiana Gulf Coastal Plain: U. S. Geol. Survey Bull. 282, 1906, p. 9.

^c Fenneman, N. M., work quoted, p. 53.

^d Harris, G. D., Rock salt: Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, p. 47.

Log of Richardson well, Grand Saline, Van Zandt County, Tex —Continued.

Material penetrated.	Thickness, feet.	Depth, feet.
Blue gray merging into bluish-black dirt with pyrite and broken limestone.....	48	83
Hard gray limestone.....	3	86
Sandy shaly clay (slate?).....	17	103
Blue clay with pyrite.....	20	123
Shale ("?).....	9	132
Shale with iron pyrite.....	5	137
Sandy shale with pyrite.....	12	149
Sandstone with pyrite.....	14	163
Hard blue limestone.....	25	188
Hard gray limestone.....	3.5	191.5
Quicksand.....	2.5	194
Alternate strata of salt and limestone.....	18	212
Rock salt.....	300	512
Bluish-gray sand.....	2	514
Black sand with water, not penetrated.....	6	520

PALESTINE

Palestine, the county seat of Anderson County, is situated in the south central part of the county on the International and Great Northern, and on the Texas State Railroads. It is in the far eastern part of the State and is about equidistant from Red River, the north line of the State, and the Gulf coast.

West of the town the land slopes toward Trinity River, and 6 miles to the southwest of the town is the saline itself, which occupies a flat measuring about 1 mile by half a mile. Around the edge of the flat incrustations of salt are observable. The surface soil is a dark or lead-colored clay, as at Grand Saline.

STEEN SALINE.

The Steen Saline is situated in the northern part of Smith County, 5 miles east of Lindale and 14 miles north of Tyler, on Saline Creek, just north of the forks. The saline proper is a small prairie 1 or 2 miles in length and one-half to three-fourths of a mile wide. The surface of the saline is covered with salt incrustations and is composed of black or grayish-black clays.

Large quantities of salt were made at this saline during the Civil War by digging shallow wells and evaporating the brine in huge kettles and boilers. According to report, as many as 20 furnaces were run at times, turning out 12,000 sacks (size unknown) of salt daily. It took 190 gallons of water to make 1 bushel of salt.^a

BROOKS SALINE

The Brooks Saline is situated in the southwestern part of Smith County, about 17 miles southwest of Tyler. It is about $2\frac{1}{2}$ miles

^a Buckley, S. B., Report of assistant State geologist: Texas Geol. and Agric. Survey First Ann. Rept., 1874, p. 126.

long and one-half to three-quarters of a mile wide. Its surface consists of blue and black clays, and around its edges is a yellow laminated clay.

OCCURRENCES OF SALT IN WESTERN TEXAS.

SALT BASIN OF TRANS-PECOS REGION.

One of the salt basins of western Texas, known as Salt Basin, has been described by Richardson.^a It is situated in the Trans-Pecos region, and the part studied lies north of the Texas Pacific Railroad in El Paso, but near Culberson County. It is west of the Guadalupe-Delaware Mountains and east of the Sierra Diablo. The basin, which trends northwest and southeast, has a total length of 150 miles, and the area described by Richardson includes 70 miles of this linear extent. The area studied is 8 to 20 miles wide, with an average width of 15 miles, and constitutes a typical inclosed basin.

The salt deposit is on the west side of the basin, about 15 miles southwest of El Capitan Peak and slightly more than 50 miles north of Van Horn. It occupies a slight depression, being one of several "salt lakes" in this part of the basin. The layer of salt that covers the surface is said to attain in places a thickness of 4 to 6 inches, but the measurements made by Richardson showed only 1 inch of commercially valuable salt. The salt is grayish white, coarsely crystalline to granular, and deliquescent. Wind-blown impurities occasionally cover its surface. During the dusty dry season the salt becomes impure, but after a rain, and especially in localities where the surface salt has been recently removed, beautiful hopper-shaped crystals are formed. Analyses^b of these salt crystals and of a typical specimen of salt from the basin are given in the following table:

Analyses of salt from Salt Basin, El Paso County, Tex.

Constituent.	[S. H. Worrell, analyst.]	Hopper-shaped crystals	Typical specimen of salt deposit.
Chlorine (Cl).....	59.5	59.0	
Sodium (Na).....	38.6	38.3	
Calcium (Ca).....	.1	Trace.	
Magnesium (Mg).....	.2	Trace.	
Sulphate radicle (SO_4).....	1.2	1.0	
Potassium (K).....		.0	
Silica (SiO_2).....		.6	
Alumina (Al_2O_3).....		.6	
Iron (Fe).....		Trace.	
Water.....	1.0	-----	
	100.6	99.5	

^a Richardson, G. B., Salt, gypsum, and petroleum in Trans-Pecos, Texas: U. S. Geol. Survey Bull. 260, 1905, pp. 573-585.

^b Richardson, G. B., work quoted, pp. 579-580.

COLORADO CITY

Salt is obtained by evaporation at Colorado City, Mitchell County, in the western part of the State. Where the Pennsylvanian and Permian beds are developed in this region numerous salt springs and wells are found. At Colorado City rock salt was found at a depth of 850 feet in drilling for water, and 140 feet of rock salt was passed through in the next 250 feet. The water in the wells rose to within about 150 feet of the surface and could not be exhausted by pumping. There has been little or no change in the character of the water since the operating company began work. The wells are cased to the first bed of rock salt at 850 feet. Fresh water was found above and below the beds of salt.

OTHER OCCURRENCES OF SALT.

During the past few years several wells have been drilled in the northwestern part of Texas in what is sometimes termed the Pan-Handle. The presence of much salt, gypsum or anhydrite, and in a few wells, small quantities of potash salts, has been revealed. The names and locations of some of the wells drilled are as follows:

S. M. Swenson & Sons well, Spur, Dickens County.
Glenario well, Glenario, Deaf Smith County.
Adrian Oil & Gas Co well, near Adrian, Oldham County.
Adrian Townsite Co well, near Adrian, Oldham County.
Boden well, Potter County.
Miller Ranch well, Randall County.
McLean well, Gray County.
Four wells in or near Childress, Childress County.
Post City well, Garza County.
Justiceburg well, Garza County.
Snyder well, Scurry County
Scoggin well, near west boundary of Kent County.
Upland well, Upton County
Buena Vista well, Pecos County
Deep well, northwest of Toyah, Reeves County.

In the north and west central parts of Texas, for example at Graham, Young County, salt has been obtained from shallow wells. The wells at Gordon, and other places in Palo Pinto County, the flowing well near Waldrup, McCulloch County, and those near San Angelo, Tom Green County, yield salty water. Along the southwestern coast, lagoons or salt lakes have yielded and can still yield a large yearly production of salt.

OKLAHOMA.

RELATIVE IMPORTANCE OF SALT INDUSTRY.

The salt industry in Oklahoma is of local importance only. During the past few years salt in the State has been produced on a small

scale near Ferguson, Blaine County, in the western part of the State, and near Salton and Vinson, Harmon County, in the extreme southwestern part.

SALT PLAINS.

SITUATION.

Salt-water wells and springs occur in eastern and western Oklahoma. In the eastern part of the State most of the water is only a little salty; in the western part the water is so salt in places that the terms "salt springs" or "salt plains" are in common usage.

The regions where the springs are situated are known as salt plains generally, and according to a recent report of the Oklahoma geological survey, 10 of these are well known, situated as follows: Two along the Cimarron River between Woods, Woodward, and Harper Counties; 2 in northwestern Harmon County; 1 each in Alfalfa, Blaine, and Beckham Counties; and 3 on Sandy Creek, south of Eldorado, Jackson County. A geological progress map^a of the State shows the surficial rocks in these regions as belonging in the Permian. Although all the salt springs of western Oklahoma issue from and probably originate in the "Red Beds," they do not all issue from the same geologic horizon.

OREGON.

No salt has been prepared in Oregon in recent years, but it is said to have been prepared from brine from springs in Willamette and Umpqua Valleys, as well as from brine from other places.^b Springs in Jackson County are also reported to have produced salt. Beds of rock salt have been reported near the base of Mount Jefferson, in Cascade Range. Alkali, Abert, and Summer Lakes contain salt in conjunction with other salines like soda and potash salts, and work for soda has been conducted in a small way around Alkali Lake.

IDAHO AND WYOMING.

Salt has been produced in Bannock and Bear Lake Counties, Idaho, in recent years. In recent years the industry has been confined to the vicinity of Stump Creek and Tyhee Valley, Bannock County, southeastern Idaho. The headquarters of most of the operators have been at Auburn, Wyo. The salt industry in this part of Idaho is of slight importance, a considerable part of the production being cattle salt. The salt has been obtained from brine springs, but beds of rock salt occur below the springs.

^a Oklahoma Geol. Survey Bull. 5, 1911.

^b Brown, J. R., Resources of the Pacific Slope, San Francisco, 1869, pp. 255-256.

NEVADA.

RELATIVE IMPORTANCE OF NEVADA SALT INDUSTRY.

The salt industry in Nevada has never been of more than local importance. Scattered salt deposits have been worked from time to time to supply local demand, but most of the enterprises yet started have been on a small scale and have been operated only spasmodically.

During recent years salt has come from Sand Springs, White Plains, Leete, and Parran, Churchill County; from the Silver Springs playa, Esmeralda County; and from the Buffalo Salt Works, Sheephead, Washoe County. Most of the salt is obtained by solar evaporation, and the finer grades like table and dairy salt and common fine salt are prepared from the solar product by different refining processes. Other known deposits are at Dixie Salt Marsh, Churchill County; Railroad Valley, Nye County; and west of Diamond Range, in Eureka and Elko Counties. Deposits of present or prospective importance are situated along Virgin River in the southeastern part of the State. In fact, numerous saline valleys are widely distributed in that part of Nevada included within the Great Basin.

NEW MEXICO.

RELATIVE IMPORTANCE OF SALT OUTPUT.

Though the commercial output of salt in New Mexico is and has been small, there is no scarcity of salt. The saline or salt-bearing lakes of this State are to be considered among its important future resources, and though little or no salt is exported, a considerable quantity of the crude product is used for salting stock. The salt thus used is gathered usually by scraping up the deposit formed about salt springs or as a thin layer on the surface of the salines or playas during the dry season. The principal lake basin deposits are those in Estancia Valley.

SITUATION OF DEPOSITS.

A small production of salt has been reported in recent years from Estancia, Torrance County. The salt basin is in the central part of the county, near the geographic center of the State. Salt is also found in flats among the gypsum ridges in what are known as the White Sand Plains of the Tularosa Basin, in parts of Dona Ana, Socorro, and Otero Counties.

The Zuni salt deposits of New Mexico are in the northwestern part of Socorro County, about 80 miles south of Gallup, on the main line of the Santa Fe Railroad and about the same distance west of Magdalena, on a branch line of the same system. The deposits have supplied Indians and Mexicans for centuries, and at present the salt is hauled to surrounding ranches. A small colony of Mexicans collect the product in a crude manner.



A. SALT MINE OF L. JACOBS, 2½ MILES NORTHWEST OF REDMOND, SEVIER COUNTY, UTAH
UNIQUE OCCURRENCE OF SALT AT SURFACE



B. SALT MINE OF INLAND CRYSTAL SALT CO IN SANPETE COUNTY, UTAH, 1 MILE NORTH
OF L. JACOBS'S MINE UNIQUE OCCURRENCE OF SALT AT SURFACE

There are many salt springs in New Mexico, but no salt is obtained from them except for limited local use. One large spring is on Rio Salada, 30 miles northwest of Albuquerque, another is 20 miles west of Belen, and a third is at the end of Malpais in Tularosa Valley, 48 miles northwest of Alamogordo. There are scores of smaller springs in the State.

The Red Beds, which underlie the Pecos Valley and Staked Plains in Eddy, Chaves, and Roosevelt Counties, contain many thick and extensive beds of salt, but are far beneath the surface. Information regarding them is derived from records of scattered borings for water or oil. These salt deposits are 300 to 500 feet thick, in heavy beds separated by layers of clay or sand, and in part of the area they lie only a few hundred feet below the surface. The 2,600-foot boring at Carlsbad in this area penetrated many thick salt beds, and they have been reached by borings east of Artesia and Roswell, as well as by numerous deep holes in the Staked Plains region in western Texas, some of them not far east of the New Mexico line.

ARIZONA.

No salt is produced at present on a commercial scale in Arizona. Common salt, as well as other chemically precipitated salts, has been deposited from the river water in the valley of Salt River with clastic sediments; and, though the salt does not form deposits geologically important, it is of great importance from its effect on the river water. The salt is thought to come from large salt springs in the upper reaches of the river. The water from these springs has been described as a weak brine.

The salt deposits in Virgin River Valley have been mentioned under Nevada. Blake^a refers to rock salt disseminated in the beds in the valley of Verde River, Yavapai County, in the south-central part of the State.

UTAH.

RELATIVE IMPORTANCE OF UTAH SALT INDUSTRY.

The nonmetallic mineral resources of Utah, like those of other western States, are still so comparatively unexplored that descriptions of almost any such deposits are necessarily incomplete. This holds true of saline deposits, particularly those of rock salt and underground brine, and in addition to those named below many others will doubtless be found.

The main salt industry in Utah is on the east shore of Great Salt Lake, at Saltair, not far from Salt Lake City, and is important and flourishing. Some salt is produced also at Garfield. All the salt now and heretofore made along the lake shore is from solar evaporation of the water of the lake.

^a Blake, W. P., Mineralogical notes Am. Jour. Sci., 3d ser., vol. 39, p. 44, 1890.

SALT-PRODUCING LOCALITIES.

The most important occurrences of salt in the State are as brine in the waters of Great Salt Lake; as rock salt in Sevier Valley, near Salina, Redmond, and Gunnison, both in Sevier and Sanpete Counties; east of Nephi, Juab County, where brine also is found; near Clear Lake in the eastern part of Millard County; and Salt Lake Desert, Tooele County. Salt is being or has been produced at all the localities mentioned. Two mines near Redmond are shown in Plate I.

GREAT SALT LAKE

Production has from time to time been reported from along the shores of Great Salt Lake, in Boxelder, Weber, Davis, and Salt Lake Counties, but with the exception of the works of the Inland Crystal Salt Co., at Saltair, on the shore of the lake 15 miles west of Salt Lake City, the operations are small and are carried on somewhat sporadically. Small amounts of salt are reported to have been gathered recently at Promontory Point, Boxelder County; at Withee, Weber County, 15 miles west of Ogden; at Syracuse, Davis County; and at Garfield, Salt Lake County. The evaporation processes employed along the lake shore to make salt are generally similar. The methods of the Inland Crystal Salt Co. are typical, as the operations at the plant of that company are by far the most elaborate.

Among other salt deposits in Utah that have come to the attention of the writer are those at Little Salt Lake, Iron County, and south of Beaver in Beaver County; and the salt marshes in Snake Valley in the western part of Millard County.

CALIFORNIA.

RELATIVE IMPORTANCE OF SALT PRODUCTION.

California ranked sixth among the States in quantity and fifth in value of the salt produced in 1915. The State has had this same relative rank during the past three years.

GENERAL OCCURRENCE OF SALT.

Salt occurs in California in practically every known form. In solution it is found in the brines of salt springs, salt lakes or marshes, and saline streams, of which certain tributaries of Salinas River, in San Luis Obispo County, are examples. In Inyo, San Bernardino, and other counties in the Great Basin many springs and streams are slightly brackish or salty. Many of the so-called alkaline or salt lakes contain water only during certain seasons of the year. During dry seasons they are covered with a crust of salt, which in many places is several inches thick. The Great Basin region contains many marshes, playas, or lakes, where salt may be collected by simply

scraping the crust. In addition to the rock salt resulting from the evaporation of saline solutions, salt undoubtedly will be found either disseminated or in segregated beds or masses buried in Quaternary lake deposits. Such deposits have originated in intermittent periods of desiccation. Rock salt occurs in a few deposits in the earlier lake beds, of which that on the north side of the Avawatz Mountains is a splendid example.

PRODUCTION OF SALT FROM SEA WATER.

More than 97 per cent of the salt made in California is from the solar evaporation of sea water along the coast. Most of the solar salt and the finer grades produced from it come from the shores of San Francisco Bay, in Alameda and San Mateo Counties. The headquarters of the salt industry are at Alvarado, Newark, Mount Eden, Russell, and Baumberg, formerly Arffs, in Alameda County, on the east shore of San Francisco Bay, and at Redwood City and San Mateo, in San Mateo County. In the southern part of the State solar salt is made at Ostend Station, near Long Beach, Los Angeles County, and on the San Diego Bay, San Diego County. The general methods of making this salt and preparing it for market are described on pages 40 to 49.

One of the main reasons for the bulk of California salt coming from along the coast is that the principal centers of population are situated there. The market is at hand and the cost of transportation is reduced to a minimum. Lack of a market and cost of transportation are the main reasons why many important deposits in the interior of the State have hitherto remained unworked.

PRODUCING LOCALITIES.

Besides the salt obtained from sea water by solar evaporation along the coast, salt has been made in small quantity in recent years at inland points as follows: Tramway (Keeler post office), Inyo County; Ward, San Bernardino County; near Saltus (Amboy post office), San Bernardino County; near Cedarville, Modoc County; at Caneda, a few miles southwest of Randsburg, and at Saltdale, Kern County.

DESCRIPTION OF OCCURRENCES.

COLUSA COUNTY.

About 25 years ago the manufacture of salt was begun at certain brine springs near Sites, Colusa County, and has continued more or less intermittently at that locality ever since, though the latest reports are that no more salt is being gathered. A number of other salt springs are known in different parts of Colusa County.

INYO COUNTY ^a

Inyo County is situated in the eastern part of California and is wholly within the boundaries of the Great Basin. In this county are included Owens Lake, Death Valley, the Saline Valley Salt Marsh, and the dried valleys of numerous other salt lakes, among which are Indian Wells Valley, Salt Wells Valley, and Panamint Valley. Though Searles Lake lies within San Bernardino County for the most part, for convenience it is here treated as being within Inyo County. Searles Lake, in former geologic time, formed a link in an ancient drainage system in which the members, beginning with the most elevated, were Owens Lake, Indian Wells Valley, Salt Wells Valley, Searles Lake, Panamint Valley, and Death Valley.

The salts found in Owens Lake, the waters of which are a dense brine, include common salt, soda, borax, and potash and other salts. According to calculation, the waters of the lake contain 160,000,000 short tons of anhydrous salts, a large part of which is sodium chloride.

The most distinctive feature of the Desert Basin, which included formerly Searles Lake, Indian Wells Valley, and Salt Wells Valley, is now Searles Lake. The immense sheet of solid white salts in its bottom is unique in this country for the variety of its saline minerals. The salt crust occupies a roughly circular area believed to be 11 or 12 square miles in extent. The depth of the salt, as shown by drillings, is fairly uniform, being reported to range from 60 feet to more than 100 feet, and to average 70 to 75 feet in the main part of the deposit. The salt deposit is in effect a consolidated mass crystallized from an evaporating mother liquor in which the salts are still immersed. The lake is one of the most promising sources of domestic potash salts.

Much saline material is accumulated on and beneath the floor of Death Valley. A central area of crusted salt lies in the lowest part of the valley and extends many miles north and south. Analyses of the saline content of the floor of the valley indicate an approximate content of 95 per cent common salt.

Salt deposits occupy the lowest part of Saline Valley, which is without outlet. Smooth, white salt deposits, about 1 square mile in areal extent, are surrounded by broken and tilted salt crust blocks with sharp, craggy surface; the salt from the smooth crust in the lowest part of the valley contains 98.52 per cent of sodium chloride, indicating that it is of high grade for a natural product.

Salt has been found at other places in Inyo County, as at Tecopa, Confidence Spring in South Death Valley, and in the canyon of Armagosa River.

^a These notes have been abstracted from a contribution by H. S. Gale, U. S. Geological Survey Bulletin 669, previously mentioned.

KERN COUNTY

In Kern County, Cameron Lake, Kane Lake, and Castac Lake are ephemeral lakes crusted with salt during the dry season. Some salt has been obtained from Kane Lake in recent years.

MONO COUNTY

Mono Lake, near the Nevada line, contains dense alkaline water. Sodium chloride or common salt constitutes nearly 35 per cent of the total solids in the lake water. Calculations based on the area of the lake and its average depth indicate that it contains nearly 90,000,000 tons of common salt, and more than 10,000,000 tons of potassium chloride.

SAN BERNARDINO COUNTY

Saltus.—Salt was produced as late as 1913 near Saltus (Amboy post office), a station on the Santa Fe Railroad in the southeastern part of San Bernardino County. The salt occurs in the bottom of an old lake bed in the form of rock-salt layers, under approximately 5 feet of overburden.

Armagosa River.—Armagosa River, for a short part of its course, flows through San Bernardino County, but the main part of the river is in Inyo County, to the northward, and within Armagosa Valley, Nye County, Nev. The term "river" is somewhat misleading, because its waters appear and disappear, being absorbed by the porous beds over and through which they flow. Though the river water is potable near its source, increasingly large quantities of various salines render it bitter, as the name Armagosa ("bitter" in Spanish) signifies. In the lower courses of the river in San Bernardino County, where the water comes to the surface, these salines are deposited as white crusts and deposits of salt and borate minerals are formed. These crusts have been removed and marketed. Some of them by natural re-solution and recrystallization have been rendered nearly pure.

Avawatz Mountains.—Rock salt outcrops on the north side of the Avawatz Mountains, in San Bernardino County, in a zone between 4 and 5 miles long, and probably underlies a large area. The salt is a member of a saline series that in upward order consists essentially of celestite, gypsum, and salt, the entire saline series being underlain and overlain with lake beds.

Where the salt has been worked its purity has increased with depth. It is massively crystalline, and is generally brownish near the surface from the presence of reddish-brown clay that owes its color to iron oxide. Some chemical analyses show the salt to be more than 98 per cent pure.

Danby.—Salt has been mined 30 miles southeast of Danby, a station on the Santa Fe Railroad, in the southeastern part of San Bernardino County, in a dry lake known as Danby Lake. Here the salt lies in two beds, each from a few inches to several feet thick, separated by a thick layer of clay and protected by a layer of sand and dust. The salt bed has been opened over an area of many acres, which forms only a small part of the deposits.

Mohave River and Sink.—The Mohave River rises in the San Bernardino Mountains, flows north and northeast through Barstow and Daggett, and more nearly east to Soda Lake, the sink of Mohave River, otherwise known as Mohave Sink. The river is about 100 miles long, and the Santa Fe and the San Pedro, Los Angeles & Salt Lake Railroads follow it for miles. Except during flood season there is little surface flow. The river waters are saline, and there are saline efflorescences all along their course. The water carries principally salt, sodium carbonate, and sodium sulphate, with small quantities of potash salts, borates, bicarbonates, silica, etc. It is reported that some salt has been made by diverting water from the surrounding hills to that part of the lake where desired. The salt is absorbed and the brine conveyed to vats and there evaporated. Only coarse salt has been marketed from the region.

Other localities.—Other localities in San Bernardino County where salt exists are (1) Bitter Springs at the southeastern end of Bitter Lake in T. 13 N., R. 5 E., San Bernardino meridian; (2) Daggett; (3) Owl Springs, which are located in the northwestern part of the county, between the west end of Avawatz Mountains and the east flank of Owl Mountains; (4) Salt Springs, on the south fork of Amargosa River, at the southeast end of Death Valley; (5) in the vicinity of Saratoga Springs, 14 miles to the northwest of Salt Springs; (6) Valley Springs, about 8 miles northwest of Saratoga Springs, the water being so salty as to be undrinkable; (7) Willards Lake. This lake is in the northwestern part of the county in Ts. 30 and 31 S., R. 42 E., Mount Diablo meridian. The beds of the lake, like those of most lakes in this region, are impregnated with salt, and the shore is marked with white crusts.

SAN LUIS OBISPO COUNTY

Soda or Salt Lake, in Carrizo Plain, contains important deposits of sodium sulphate, with which small quantities of ordinary salt are associated. Carrizo Plain is near the northeastern boundary of San Bernardino County, and the lake is in T. 31 S., Rs. 19 and 20 E. The saline deposits are estimated to cover an area of approximately 3,000 acres. The exploitation of the deposits for sodium sulphate was discontinued a few years ago.

OTHER LOCALITIES ^a

Other localities in the State where salt has been reported to be found in small quantities are as follows:

Calaveras County.—There are salt springs on the Mokelumne River, 6 miles south of Silver Lake.

Contra Costa County.—Alhambra Mineral Springs.

Humboldt County.—Eureka Springs.

Lake County.—Allen Spring, Borax Lake, Lake Hachinham, Hot Borate Spring, Clear Lake, Howard Spring, and Siegler Spring.

Los Angeles County.—According to Bailey^b there are large salt springs 14 miles from the city of Los Angeles, the exact location not being given.

Modoc County.—Near Cedarville.

Napa County.—Aetna Springs, Calistoga Springs, White Sulphur Springs.

Placer County.—Salt Springs are reported near the Clipper Cap Iron Mine.

San Benito County.—Anderson's Springs.

Santa Clara County.—Pacific Congress Springs, Alum Spring, Azule Spring, Blodgett Spring, near Gilroy, New Almaden Spring.

Shasta County.—Salt was made at one time on Salt or Stinking Creek, 12 miles east of Redding.

Siskiyou County.—Strong brine is reported to flow from a well, 675 feet deep, near Yreka.

Solano County.—Tolena Springs.

Sonoma County.—Santa Rosa Spring, Skagg's Springs, White Sulphur Spring.

Tehama County.—Tuscan Springs, Little Salt Creek.

^a Doubtless this list will now be found incomplete, and the author will welcome communications that will add to its accuracy.

^b Bailey, G. F., The saline deposits of California, Cal. State Min. Bureau Bull. 24, May, 1902, p. 136.

SALT-MAKING PROCESSES.

CLASSIFICATION.

The processes of salt making in the United States are of two kinds: (1) The mining of rock salt and its purification and separation into marketable sizes, and (2) the production of salt by evaporation from brines, bitters, and other solutions containing it. The processes employed in the manufacture of salt by evaporation may be classified as follows:

- 1 Solar evaporation
- 2 Direct-heat evaporation:
 - (a) In open kettles.
 - (b) In open pans
- 3 Steam evaporation
 - (a) In jacketed kettles.
 - (b) In grainers
4. Vacuum-pan evaporation

SOLAR EVAPORATION.

WHERE PROCESS IS USED.

In the eastern States solar evaporation is not general because of the climate, and is confined, so far as the writer knows, to New York State. In the western States, and particularly in California and Utah, the process is extensively used.

SOLAR EVAPORATION AT SYRACUSE, N. Y.^a

COMMERCIAL STATUS OF INDUSTRY.

The manufacture of salt by solar evaporation began in New York in the vicinity of Syracuse, Onondaga County, in 1789, and the process is limited to Syracuse and vicinity, where it has survived from early days. Though only a small part of the evaporated salt manufactured in New York is now made by the solar process, before 1880, when the beds of rock salt in the western part of the State began to be utilized, Onondaga County supplied the entire output of the State in rock (coarse) salt. The greater part of the total now returned for the county represents the salt in brine consumed in the manufacture of soda. The solar salt produced is mainly coarse salt, and is used for practically the same purposes as

^a In the preparation of this section the author has made free use of the works of F. E. Englehardt, The manufacture of salt in the State of New York. New York State Mus. Bull 11 1893, pp 38-44, and T M. Chatard, Salt-making processes in the United States. U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 497-527.

rock salt. It is marketed through the Onondaga Coarse Salt Association.

The wells are on lands once included in the Onondaga Indian Reservation, and until recently the State supplied the brine to individual plants, exacting a small tax on the product to cover costs of pumping and supervision. However, in 1908, the lands and wells were sold to the Onondaga Pipe Line Co. and the Mutual Pipe Line Co. of Syracuse. This transfer definitely terminated the long connection of the State with salt making.

Solar salt is made from a natural brine—the only instance of its use in New York. The process, of course, is carried on only during the spring, summer, and fall months, usually from the middle of March to the middle of November, depending on the weather.

The increased value of the enormous acreage covered by the plant and the higher charges for labor, lumber, taxes, and insurance have appreciably decreased the returns from solar evaporation in the State.

ORIGINAL METHOD.

Formerly solar salt was made in shallow wooden vats or "covers," provided with light movable roofs running on rollers. (See Pl. II.) During the evaporating season the roofs were moved to one side, but were replaced during rainy weather and at the end of the salt-making season. The natural brine containing 17 to 20 per cent sodium chloride (68° to 80° salometer) flowed successively to three sets of vats or "rooms" known, respectively, as deep rooms, lime rooms, and salt rooms, about two-thirds of the space in a salt yard being given to salt rooms. The rooms were generally 18 feet wide and their length, or the length of a "string" (series) of them, depended on the length of the salt yard, which was often as much as 400 or 500 feet. The lime and salt rooms were 6 inches and the deep rooms 12 to 14 inches deep. The movable covers of the rooms were built in 16-foot sections, thus covering an area of 288 square feet. In the larger and longer yards the floor of each salt room was 6 or 8 inches higher than that of the next below. The advantages of this arrangement were that the fresher pickle could be regularly separated by gravity from the older, and that after the pickle in the lowest room had been removed during harvesting, fresher pickle could be drawn into the room to remove adhering chloride of magnesium and crystals of gypsum from part of the salt.

When the brine was first pumped into the deep rooms, which served mainly for storage, it was usually clear, but with the escape of gases (mostly carbon dioxide) ferrous carbonate separated, which on oxidation to the hydrated ferric oxide settled out as a yellow mud, leaving the brine again clear. The brine then flowed into the lime rooms, where evaporation continued until the brine became saturated and salt crystals began to separate. During this process,

particularly near the time of complete saturation, gypsum began to separate. The term "lime room," which is somewhat misleading, as no lime was used in the process, was probably applied because of gypsum separating in the room. The brine, then known as "pickle," flowed to the salt rooms, where the salt and the remainder of the gypsum separated, sufficient pickle being added from the lime room from time to time to keep the salt crystals well covered. The salt crystals were finally gathered from the floor of the salt room after the mother liquor had been drawn off.

IMPROVED METHOD.

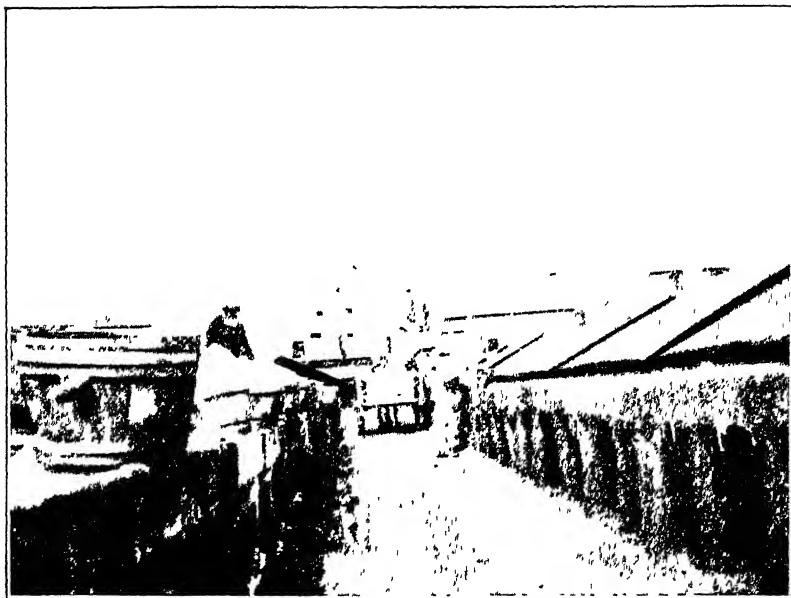
Great improvements have been made in the original method of solar evaporation, one of the greatest being the use of "aprons" in place of the deep rooms and the lime rooms, whereby the evaporating surface and the yield of salt per cover (288 square feet) have been greatly increased. The aprons are shallow wooden troughs 3 inches deep, 15 to 20 feet wide, and of various lengths. (See Pl. II.) They are generally erected over the deep rooms and serve as roofs as well as storerooms for the saturated brines of the deep rooms. They are built on piles or posts and are sloped 1 inch in 100 feet, so that the liquid in them flows toward two sets of holes provided with wooden plugs. One set of holes communicates with the deep rooms and the other with the waste drain. The brine run into the aprons often becomes saturated in one good drying day. It is then discharged into the deep room below and its place is taken by fresh brine. When rain is expected the plugs over the deep rooms are removed and the brine, flowing from the aprons, is thus saved from dilution. These plugs are then replaced and the other set is removed, the rain being thus allowed to flow to waste. The partly concentrated brine is returned to the aprons by pumps when clear weather returns. The process is carried on usually from the middle of March to the middle of November, the exact period depending on the weather.

The brine is thus concentrated and purified while it is being transported to the "covers." The great length and width of the aprons, the shallowness of the brine, and its complete exposure to the sun, air, and wind greatly facilitate purification and evaporation; also they permit the use of the entire number of "covers" for salt making, instead of one-third of the total cover area being occupied by lime rooms and deep rooms. This improvement greatly increased the production of solar salt per cover and, as considerable capital is invested in covers, the economy of the process is obvious.

RECOVERY OF SEA SALT IN CALIFORNIA.

PRODUCTION CENTERS.

More than 97 per cent of the output of salt in California originates from the solar evaporation of sea water along the coast. The largest



A. HARVESTING SALT PRODUCED BY SOLAR EVAPORATION AT SYRACUSE, N Y



B SALT VATS WITH ROOFS REMOVED, SOLAR EVAPORATION PROCESS, SYRACUSE, N Y

plants are along the east and west shores of San Francisco Bay, in Alameda and San Mateo Counties, respectively. In Alameda County the centers of production are near Alvarado, Mount Eden, Russell, Baumberg (formerly Arffs), and Newark; in San Mateo County solar salt is produced a short distance south of San Mateo, near Redwood City. Other solar plants are at Ostend Station, near Long Beach, Los Angeles County, and on San Diego Bay, San Diego County. At all these places the operations are conducted in somewhat similar manner, although differing considerably in details. Also the nomenclature of the processes varies somewhat. The following general description of the processes is based on observations at representative plants in different localities.

SALT-MAKING SEASON.

The concentration of the water in San Francisco Bay varies with the season of the year and other factors. The water of the bay is diluted somewhat by fresh water from San Joaquin and Sacramento Rivers, the dilution being increased after winters of heavy snow, which does not completely melt until summer is well advanced. Brine is taken into the salt ponds around San Francisco Bay from the middle of May to the middle of October, but the strongest brines are obtained after the 1st of July, as the dry season lengthens and the inflow of fresh water from the rivers appreciably declines. Generally the salt-making season is over by September 15, as the dry season lasts usually from May to September. However, a season as long as 210 days without rain has been known along San Francisco Bay.

The mean average date when crystallization of salt began around San Francisco Bay was May 1 in 1908, May 13 in 1909, May 3 in 1910, May 25 in 1911, and April 18 in 1912. The early date in 1912 was because of few late rains that year. Records are closed, that is, evaporation readings are stopped, November 1, after which the days are so short, the water is so cold, and the weather so uncertain that there is practically no evaporation.

During the summer season of 1911, which may be taken for purposes of illustration, the evaporation and rainfall observed at one plant were as follows:

Rainfall and evaporation, in inches, season of 1911, San Francisco Bay, Cal.

Month.	Rainfall		Evapora- tion Inches.
	Inches.	Inches.	
April.....	1.36	3.38	
May.....	1.14	5.31	
June.....	.67	6.62	
July.....	.00	7.81	
August.....	.00	7.81	
September.....	.00	4.94	
October.....	.77	2.94	

The water from the bay or ocean is not taken into the works continuously but during two to six days a month, when the tides are highest, usually at the period of new moon. During high tide water is run into the ponds one and one-half to three hours. At some plants where a slough^a runs through the intake pond salt water may be taken in at any time or every day. Thus at Long Beach the sea water runs into a ditch at every high tide; that is, twice a day. Salt water may therefore be pumped continuously from this ditch into the plant.

The salt-making season is naturally longer in southern California than near San Francisco. At San Diego it lasts about seven months, from May to November, and salt water also may be taken in continuously by draining the tide ponds, into which sea water enters during every tide above a given height.

STRENGTH OF BRINE.

The average density of sea water is 1.027, corresponding to a salinity of 3.72 per cent regarded as pure salt. Three samples of bay water collected as they ran into plants on the shores of San Francisco Bay and on San Diego Bay gave results as follows:

Density and salinity of sea water used in salt making, California

Source	Date of collection	Density.	Specific gravity. ^a	Percentage of salt ^b
San Francisco Bay at Mount Eden.	1912	° B.		
San Francisco Bay at Alvarado.	Oct. 5	3.53	1.025	3.44
San Diego Bay.	8	3.12	1.022	3.34
Sea water.	17	4.10	1.029	4.00
	.....	.....	1.027	3.72

^a Specific gravities were taken at 22° C., but are referred to water at 15° C.

^b Assumed to be pure NaCl, which is not exactly correct.

The normal salt water entering the salt plants along San Francisco Bay is less strongly concentrated than ordinary sea water, whereas the bay water near San Diego is more strongly saturated. The difference in density between waters from San Francisco Bay and those from San Diego Bay is caused partly by the fact that farther south the warm dry season lasts much longer and consequently evaporation is more intense, and partly by the fact that streams of fresh water flow into San Francisco Bay.

SALT PONDS

Salt is made in ponds which are designated according to the operations taking place in them; thus there are the storage, intake, receiving, or tide ponds into which the salt water is received from the bay, the concentrating ponds, and the crystallizing ponds (Pls. III, IV,

^a The term slough is applied to an artificial canal, ditch, channel, or inlet

and V). All ponds between the tide ponds and the crystallizing ponds are called secondary ponds by some operators; technically they may be termed pickling ponds. The term lime ponds is sometimes applied to those in which the bulk of the gypsum crystallizes.

The sea water enters the works, generally through a slough, into the intake, receiving, storage, or tide pond, which is provided with large flood gates that automatically open when the water can run in and close as the tide ebbs. In the intake pond the salt water remains and evaporates a variable length of time before the next salt water is taken in, and goes through the different ponds, gradually getting more concentrated, until it finally reaches the crystallizing ponds. It is run into these to a depth of about 6 inches when it has reached a strength of about 25° B., or when crystals of salt have begun to form. At some plants when the pickle in the salt ponds has reached a strength of 29° B., the bittern with some salt still in it is run into other ponds, where it evaporates until a concentration of 32° B. is reached. As it is generally believed that all the salt is then out of the mother liquor, it is allowed to go to waste, but in view of its composition as given on pp. 47 and 48, recovery of magnesia and potash salts ought seemingly to be profitable if undertaken on a comprehensive scale. At some plants part of the mother liquor is utilized, as will be seen by referring to p. 46, and indications are that the future will see a general utilization of what for years has been a waste product.

Specific gravity of bitterns from crystallizing ponds of California.

Locality	Density at 22° C.	Specific gravity α
Oliver plant, Mount Eden.....	32.50	1.288
Leslie Salt Co., San Mateo.....	29.60	1.256
California Salt Co., Alvarado.....	27.21	1.231
Long Beach Salt Co., Long Beach.....	28.00	1.239
Do.....	28.60	1.245
Western Salt Co., San Diego Bay	27.50	1.234

◆ Specific gravities were determined at 22° C. by R. K. Bailey with a Westphal balance, but they are referred to water at 15° C.

Pond area is one of the dominant features of the industry. The total acreage of ponds at a few plants is as small as 500 acres, but at others it is reported to be more than 2,000 acres. The ratio of the area of crystallizing ponds to that of the whole system at two large plants is 1 to 10. The older works have more ground available for crystallizing beds because the ground becomes more thoroughly salted and consequently harder and less pervious with continued use.

The ponds have mud floors and are separated from one another by low embankments or dikes that differ greatly in width and height. The dikes may be as much as 3 feet above the level of the marsh and

1 or 2 feet above the level of the brine. Some are very narrow, but others, especially some of the outside dikes, are so wide and well built that they serve as roadways. Low narrow dikes are not considered good by all the salt makers, as they require frequent repair to meet the constant wash of the waves. However, if the levees are too high they may hinder the evaporating action of the wind, but there is not much wind at San Diego. The dikes between the ponds were formerly flanked with sod, but this practice is being abandoned.

METHODS OF PUMPING.

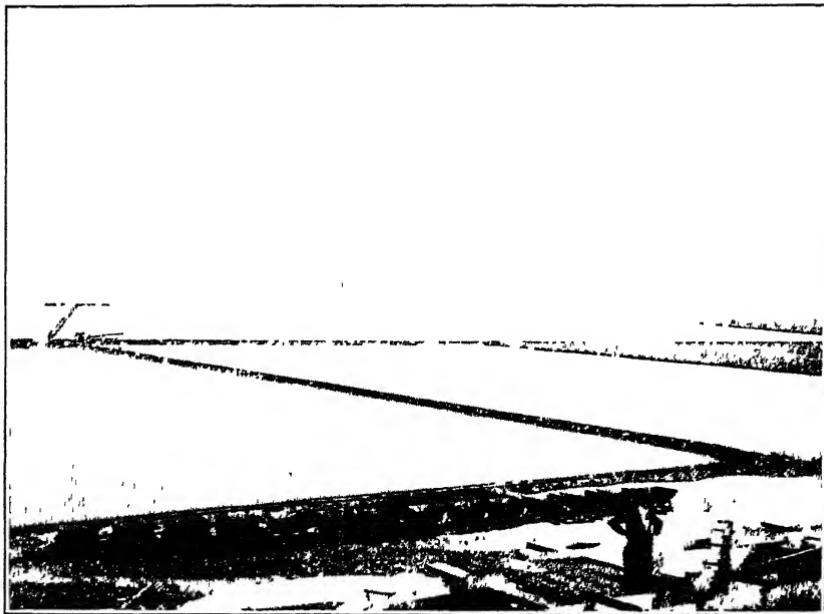
The brine around San Francisco Bay is raised partly by Archimedean screws propelled by windmills (Pl. VI) and partly by paddle wheels, some plants having as many as 40 windmills. Some plants use gasoline engines as auxiliary power, especially in the fall after the trade winds die down and in August when the trade winds slacken or blow intermittently. Electric power is also coming into use.

The windmills face northwest, from which direction the trade winds come. The pumps are generally placed so as to pump from the intake pond into a pond high enough to allow the brine to move by gravity (Pl. IV, A), the flow from one pond to the next being controlled by small gates. Windmills or other means may, however, be used for lifting in parts of the system where utilization of gravity is inexpedient (Pl. VI).

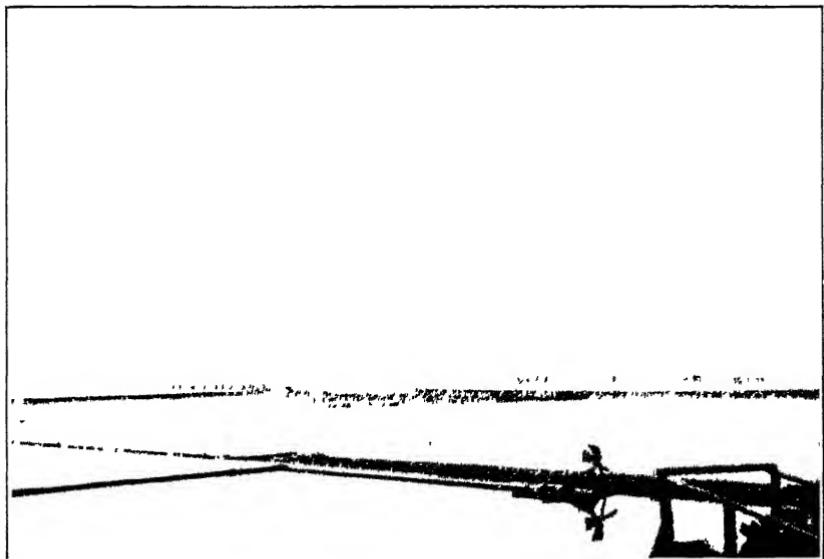
HARVESTING

The crop of salt is usually sold before July of the following season. Enough salt is thereafter gathered from time to time to supply the current demand until September, when harvesting (Pls. VII and VIII) is pushed as vigorously as possible. At many plants the first salt is lifted about the first of June and the operation is continued until about the first of January or February of the following year if the crop is big and labor is rather scarce; ordinarily, however, harvesting is finished by December.

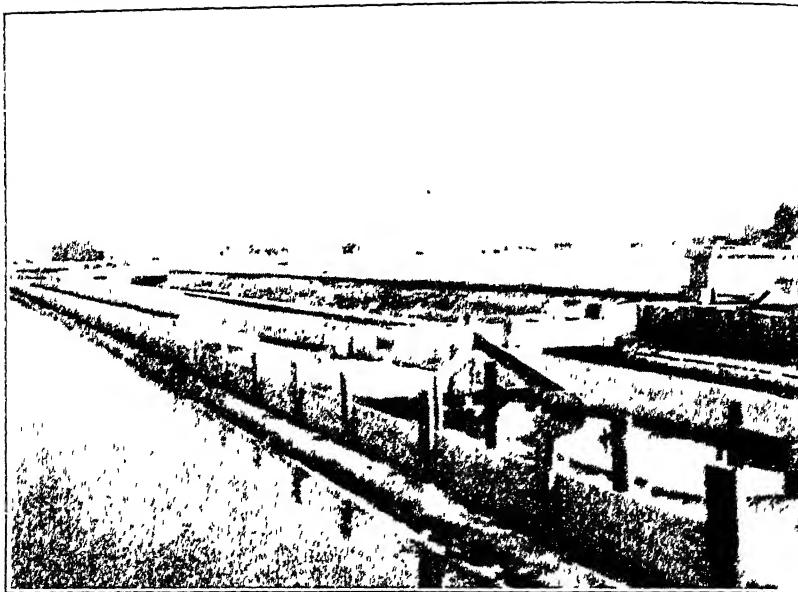
Usually the salt deposit is first harvested to within .2 inches of the mud floor; then the remaining lower grade is harvested separately and is sold for making ice cream and for stock. The salt is shoveled into tram cars holding about a ton. The salt thus lifted has a pinkish hue, and the mother liquors are likewise pinkish. A small locomotive propelled by gasoline or electricity then hauls 6 or 8 cars to the mill or to the salt piles or stacks. Small stacks are made at some plants, and at others one huge stack is made near the mill (Pl. IX, A). The latter method is doubtless more economical, for it reduces both the surface exposed to solution by rain and also that which has to be broken in subsequent utilization of the salt. The latter consideration is important, for the surface hardens so firmly that it can be broken only with the greatest difficulty; indeed, the cost of breaking a par-



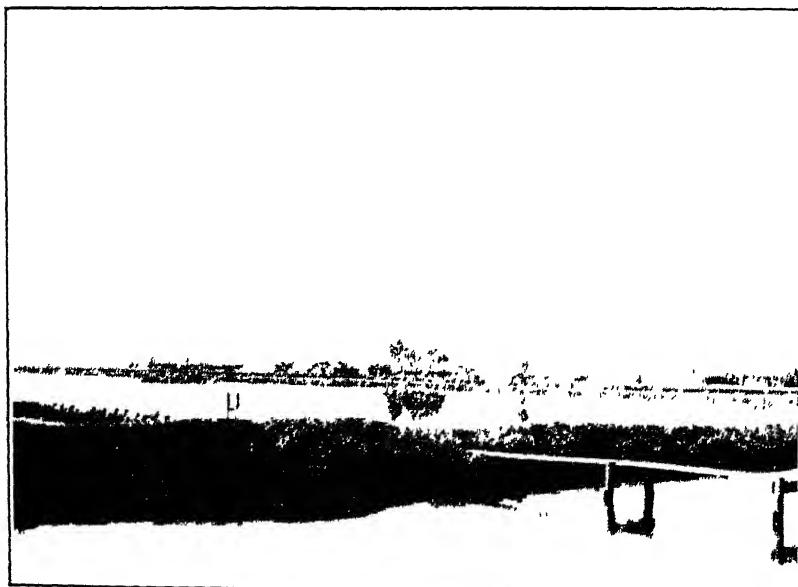
A VIEW OF CRYSTALLIZING PONDS, SHOWING ONE FIELD READY TO BE HARVESTED
LESLIE SALT CO., SAN MATEO, CAL.



B SALT PONDS AND SALT PILES AT PLANT OF UNION PACIFIC SALT CO., SAN FRANCISCO
BAY, CAL.



A GRAVITY METHOD OF RUNNING BRINE FROM ONE POND TO ANOTHER OLIVER SALT CO PLANT, MOUNT EDEN, CAL.



B SALT GARDENS, OLIVER SALT PLANT, MOUNT EDEN, CAL.

ticularly old crust on a small stack is sometimes more than the salt is worth and some old small stacks have been discarded for that reason. The salt in some stock piles hardens so firmly that cross-cut saws are used to cut it into 4-foot lengths, which are pried apart and crushed in the subsequent milling.

At some mills the salt is dumped through a hopper to a screw conveyor, which carries it to a bucket elevator that lifts it to the main stack. Not every plant can use this method, for the ground has to be very firm to accommodate the enormous tonnage of one main stack—a condition not common in regions of marshy land. Sinking of the ground may cause loss of an appreciable part of the product. At one mill the filling sank 1 foot a year for 20 years.

At one plant the salt is shoveled by laborers, a line of whom extend the width of a pond, onto an endless belt 20 inches wide, running on rollers and operated by a gasoline engine, which conveys the salt to one side of the pond. As the salt leaves the belt it is washed with a spray of salt water from the bay (Pl. IX, *B*). Then it is dragged up a perforated copper screen by an endless drag chain provided with forks to break up the larger lumps. During the ascent the salt is again washed with bay water. The salt is then raised to the stacks by a pan elevator so run that the open mouths of the pan are reversed to enable the excess of wash water to drain. The main belt, which conveys the salt from the pond, is kept perfectly clean by a washing device. The salt from the outside stock piles is brought to the mill as needed in 5-ton cars. This method has many advantages. As soon as a given area of salt has been removed from the crystallizing ponds the entire layout is moved forward on tracks, and the salt pile may thus be extended the length of the pond. The washing of the salt is also performed when the adhering bittern is most readily and completely removed.

At Long Beach the salt is shoveled from the stock pile into small cars, which are carried by a rope tram to a crusher in which the salt is ground. A bucket conveyor takes the salt to a bin in an ordinary freight car, which is hauled by a motor to the mill when the bin is full.

At San Diego the salt in the crystallizing pond has to be broken with a pickax before it can be shoveled, the greater firmness of the crystals as compared with those of the salt along San Francisco Bay possibly being due to quicker crystallization. It is customary to begin harvesting as soon as the bittern is drained from the crystallizing ponds, as the salt is easier to pick, shovel, and wash at this stage than at any other.

The yield during a season varies from year to year, being governed by the weather and other factors. A thickness of 5 or 6 inches of salt a season would be a fair approximation for the region around

San Francisco Bay, but in the southern part of the State, owing to the longer and dryer season, it would be much larger. At San Diego, for example, an average harvest is 6 inches of salt, and two such harvests can be gathered each season.

MILLING.

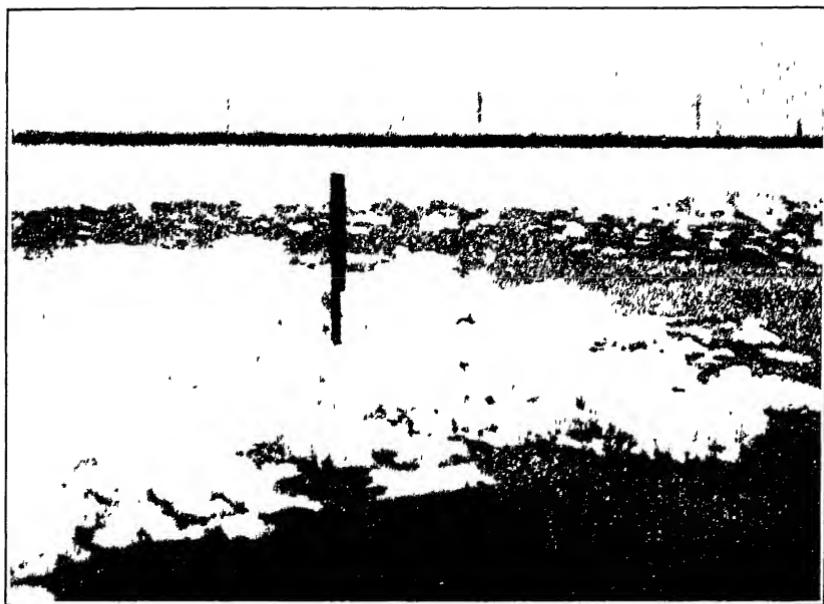
Because of the nature of the processes employed in the manufacture of solar salt, and more particularly because of the differences between them and those employed in other parts of the United States, the first stages of the milling operations in California differ from corresponding operations elsewhere. When the salt is lifted from the crystallizing ponds it is contaminated with considerable adhering pickle or bittern and dirt of various kinds. If it is not to be used at once it may undergo a preliminary washing, after which it is conveyed to the stacks. If it is to be used immediately it is carried to the mill and there washed to free it from adhering impurities.

Washing is accomplished in various ways. The salt may be dumped into a hopper and a current of hot brine from the pickling pond poured over it. The brine is bay water concentrated to complete saturation, and therefore for a concentrated solution it contains the least amount of mother-liquor salts and consequently dissolves a minimum amount of salt during the washing. An elevator lifts the salt from the hopper, the salt draining in the meanwhile. Then the salt passes between rolls which crush it into "half-ground salt" or "three-quarters ground salt." Next it goes to vats filled with artificial brine that is made from salt and fresh water and consequently contains no mother-liquor salts. On removal from these vats the salt is stacked in heaps to drain. The coarse salt is then sacked for one branch of the trade. If it is to be subjected to further refining the salt goes from the vats to a centrifugal machine, by which adhering water is removed. It is then conveyed to driers, which are long revolving cylinders containing steam coils and provided with fans that pump warm air through. From the driers the salt goes again to the rolls to be crushed and finally to the sifters to be graded according to fineness. It is then ready to be sacked for the trade.

Operations at different plants differ greatly in details. At some plants the salt in the stock piles is redissolved and the finer grades are made by the vacuum-pan process; then the manipulation of the salt at the mill may be quite different from that just outlined.

UTILIZATION OF BITTEN

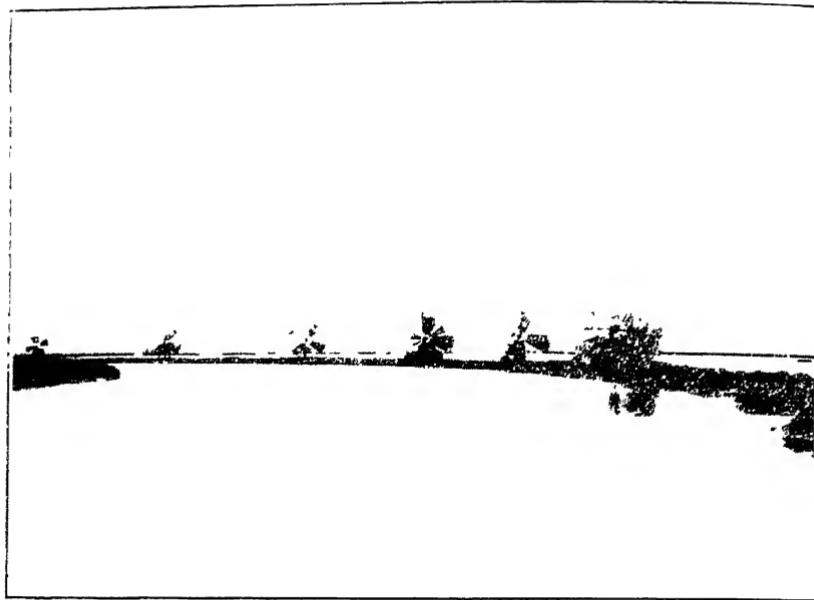
The bittern from the crystallizing ponds has never been saved at some of the plants, and at most of them it is even now entirely wasted. Since the value of potash salts has been realized, some operators have had in mind recovery of the potash in the bitterns, but few have



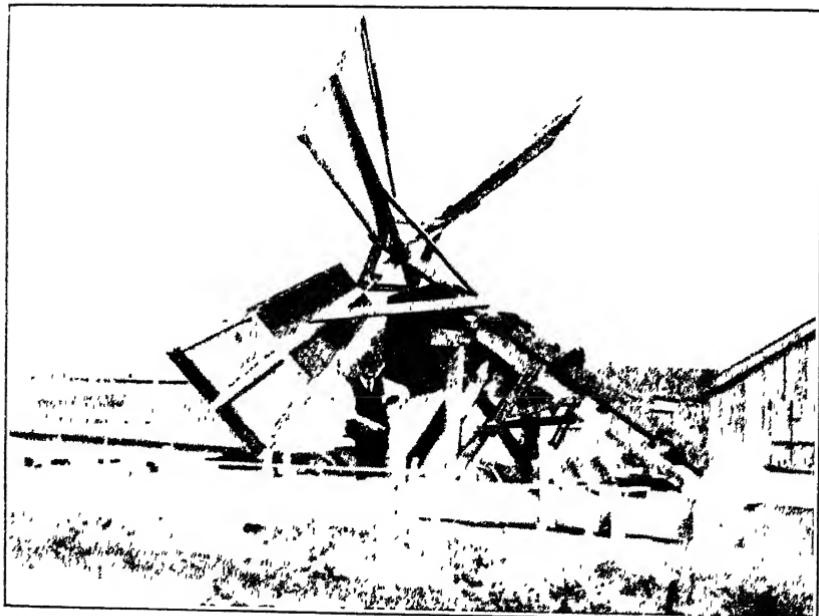
A SALT CRYSTALLIZATION IN CRYSTALLIZING PONDS, LESLIE SALT CO., SAN MATEO, CAL



B CRYSTALLIZING PONDS AT LESLIE PLANT, SAN MATEO, CAL., SHOWING METHOD OF TRANSPORTING RAILS FOR LAYING NEW TRACKS



A SLOUGH AND WINDMILLS AT OLIVER SALT PLANT, MOUNT EDEN, CAL



B WINDMILL, OLIVER SALT PLANT, MOUNT EDEN, CAL

evolved definite methods for obtaining this by-product. It is reported that the Leslie Salt Refining Co., in conjunction with the Whitney Chemical Co., has begun to manufacture epsom salts, magnesium chloride, and potash salts from residual bittersns.^a

Edward B. Durham,^b of Berkeley, Cal., and doubtless many others, have also experimented with the residual bittersns from the manufacture of salt along San Francisco Bay and southern California. Durham has separated the magnesium from these bittersns in the form of magnesium carbonate, making use of sal soda. By this process the potash salts are left in the filtrate from the magnesium carbonate.

As the price of magnesium chloride has been high on the Pacific coast during the war, separation of this chloride as well as the sulphate from these bittersns has also been considered. The artificial carnallite produced in the process would also be utilized.

At one plant a small part of the bittersn is refined for medicinal use; at another it has been used in the manufacture of "wood stone" and magnesium oxychloride cement. The latter substance is an excellent nonconductor of electricity and has been utilized in the manufacture of switchboards. It is understood that bittersn has been used by the Santa Fe Railroad to lay the dust along its roadbed, but this use is not economical because the bittersn has to be applied frequently.

In the table following are given analyses of the bittersn obtained in connection with the manufacture of salt on the California coast.

Analyses of bittersns from sea water.

[Samples collected by E. E. Free in 1912; R. F. Gardiner, analyst.]

RADICALS IN GRAMS PER LITER.

Constituent	Sample No.							
	1	2	3	4	5	6	7	8
K.	8.2	13.4	13.2	14.6	21.5	35.0	11.8	0.7
Na.	80.0	75.8	38.8	27.7	9.1	93.6	60.1	61.0
Ca.	1.2	2.2	.6	5	1.0	2	1.1	Trace.
Mg.	24.0	23.4	50.6	62.7	79.4	8.6	43.9	24.8
Cl.	179.2	176.6	179.4	188.3	220.1	180.4	190.8	148.5
SO ₄ .	30.0	31.4	53.6	74.2	62.0	29.0	55.8	34.1
Br.	3.0	3.0	3.0	3.0	2.0	2.0	2.8	.....
	325.6	325.8	339.2	366.0	395.1	348.8	366.3	269.1

CONVENTIONAL COMBINATIONS IN GRAMS PER LITER.

KCl.	15.6	25.5	25.2	27.8	41.0	66.7	22.5	1.3
NaCl.	203.0	192.7	98.6	70.4	23.1	240.0	152.7	160.4
MgCl ₂ .	65.0	63.8	144.5	171.1	250.6	4.2	117.5	63.5
CaSO ₄ .	4.0	7.4	2.3	1.7	3.3	.6	3.7	Trace.
MgSO ₄ .	33.9	32.8	65.0	91.5	75.3	35.8	66.7	42.7
MgBr ₂ .	3.4	3.4	3.4	3.4	2.3	2.3	3.2	.....
	324.9	325.6	339.0	365.9	395.6	349.6	366.3	267.9

^a American Fertilizer, New potash factory: vol. 45, Sept. 30, 1916, p. 48.

^b Personal communication.

^c Grams per kilogram.

Analyses of bitters from sea water—Continued.

RADICALS IN PERCENTAGE OF ANHYDROUS RESIDUE

Constituent.	Sample No							
	1	2	3	4	5	6	7	a 8
K	2 51	4 11	3 89	3 99	5 44	10 03	3 22	0 25
Na	24 37	23 27	11 45	7 57	2 30	26 83	16 41	22 68
Ca	37	.68	18	14	26	.06	30	00
Mg	7 38	7 18	14 92	17 13	20 09	2 47	11 98	9 21
Cl	55 03	54 20	52 88	50 07	55 71	51 72	52 10	55 19
SO ₄	9 22	9 64	15 80	20 28	15 69	8 32	15 23	12 67
Br	92	92	88	82	51	.57	76	.....
	100 00	100 00	100 00	100 00	100 00	100 00	100 00	100 00

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF ANHYDROUS RESIDUE

KCl	4 80	7.83	7 43	7.60	10 37	19.07	6 14	0 48
NaCl	62 48	59 19	29 09	19 24	5 84	68 65	41 69	59 88
MgCl ₂	20 00	19 60	42 62	46.77	68 35	1 20	32 09	23 70
CaSO ₄	1 23	2.27	68	.46	.83	.17	1 01	00
MgSO ₄	10 44	10.07	19 18	25 00	19 03	10 24	18.20	15 94
MgBr ₂	1 05	1 04	1 00	.93	.58	.66	.87	—
	100 00	100 00	100 00	100.00	100 00	100.00	100 00	100 00

^a Grams per kilogram

SOURCE OF SAMPLES.

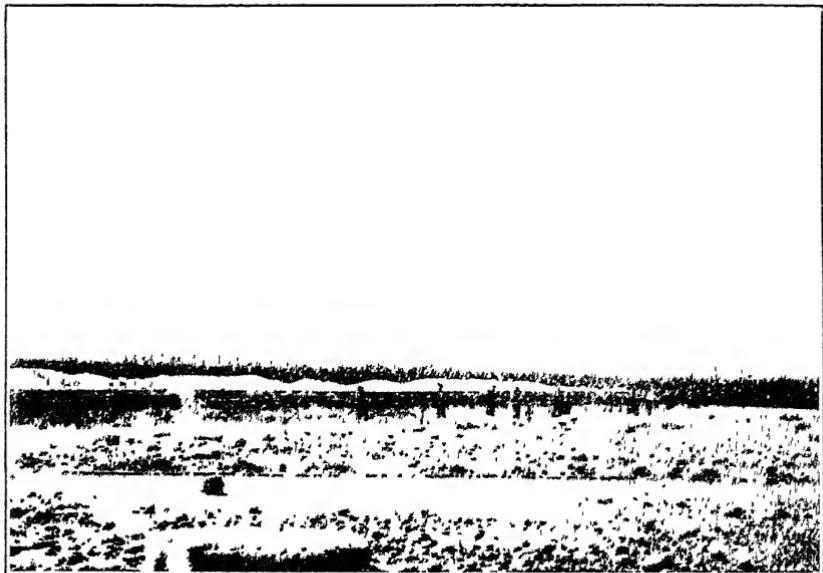
1. Leslie Salt Refining Works, San Mateo, Cal. Representative sample taken near northwest corner of mother-liquor pond
2. Leslie Salt Refining Works, San Mateo, Cal. From southeast corner of mother-liquor pond.
3. Leslie Salt Refining Works, San Mateo, Cal. From salt-making pond, in which salt had been forming during the summer.
4. Oliver Salt Works, Mount Eden, Cal. From slop pond, representing 5 years' accumulation.
5. Oliver Salt Works, Mount Eden, Cal. Mother liquor that had been subjected to special treatment
6. California Salt Co., Alvarado, Cal. From slop pond, representing 3 years' accumulation, though considerable quantities had been abstracted and small quantities of other waste liquors had been added.
7. Pioneer Salt Co., San Francisco, Cal. One year's accumulation
8. Long Beach Salt Co., Long Beach, Cal. Abnormally concentrated bittern from an outlying tank, 1912, R. K. Bailey, analyst

NOTES ON SAMPLES

The analyses of the bitters resulting from the extraction of salt from sea water on the California coast are remarkable for the indicated proportion of magnesium salts, both the chloride and the sulphate, and also for the rather large proportion of potassium. Calcium is present in very small proportions, probably in the form of sulphate. Bromine is present in relatively small proportions. The relatively large content of potassium makes it probable that these bitters might be evaporated and utilized in the manufacture of low-grade fertilizer material, such as manure salts, hartsalz, and kainite.



A LOADING SALT ON SMALL CARS TO BE CARRIED TO THE PLANT FOR REFINING, AT OLIVER SALT PLANT, MOUNT EDEN, CAL



B HARVESTING SALT IN THE HARVESTING POND OF THE LONG BEACH SALT CO., LONG BEACH, CAL



PANORAMIC VIEW SHOWING SALT PONDS DURING HARVESTING PROCESS, LONG BEACH SALT CO., LONG BEACH, CAL.

SALT PRODUCTION AT GREAT SALT LAKE, UTAH.

PRODUCTION CENTERS.

Salt has been made by solar evaporation for many years along the shores of Great Salt Lake, the industry dating in fact from the early settlement of the region. A small amount of salt is reported as having been made recently at Promontory Point, Box Elder County; Withee, Weber County; Syracuse, Davis County; and at Garfield, Salt Lake County. The most elaborate operations ever attempted along the lake shore are conducted at the plant of the Inland Crystal Salt Co., near Saltair, 15 miles west of Salt Lake City. The process of obtaining salt near Saltair is described below.

CHARACTER OF BRINE

The chief differences in the results of various chemists who have analyzed the water of Great Salt Lake are in the degree, but not in the character of the salinity. It is to be expected that the concentration would change with changes in dilution from local sources. The water of Great Salt Lake, which is the brine utilized, is similar in composition to sea water, though its concentration is four to seven times that of sea water, and consequently it furnishes a much stronger brine for salt making. (See analyses below.) A sample from the lake north of Lucin Cut-Off, near Withee Junction, Utah, collected by the writer in 1912, had a salinity of 13.35 per cent, according to a test by R. K. Bailey.

The following analyses tabulated by Clarke^a show the composition of the water. Other analyses are given by Gilbert.^b

Analyses of water from Great Salt Lake.

Constituent	Sample No								
	1	2	3	4	5	6	7	8	9
Cl.....	55.99	56.21	55.57	56.54	55.60	55.25	55.11	53.72	55.48
Br.....	Trace	.....	.....	.....	Trace	.....	.....	.....	.....
SO ₄	6.57	6.89	6.86	5.97	6.52	6.73	6.66	5.95	6.58
CO ₃	0.07	.....	.....	.....	0.01	.....	.....	.....	0.09
Li.....	Trace	.....	.....	.....	.....	Trace	.....	.....	.....
Na.....	33.15	33.45	33.17	33.39	32.92	34.65	32.97	32.81	33.17
K.....	1.60	(?)	1.59	1.08	1.70	2.64	3.13	3.1	1.66
Ca.....	.17	.20	.21	.42	1.05	1.16	.17	.31	.16
Mg.....	2.52	3.18	2.60	2.60	2.10	.57	1.96	2.22	2.76
Fe ₂ O ₃ , Al ₂ O ₃ , SiO ₂.....	.....	.....	.....	.....	0.01	.....	.....	.....	.....
Salinity, per cent.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	14.994	13.790	15.671	19.558	c23.036	27.72	22.99	17.68	20.349

^a Clarke, F. W., The data of geochemistry U S Geol Survey Bull 491, 1911, p 144, and Bull. 616, 1916, p 155.

^b Gilbert, G. K., Lake Bonneville U S Geol Survey Mon 1, 1890, pp 253-254

^c More correctly, 230.355 grams per liter.

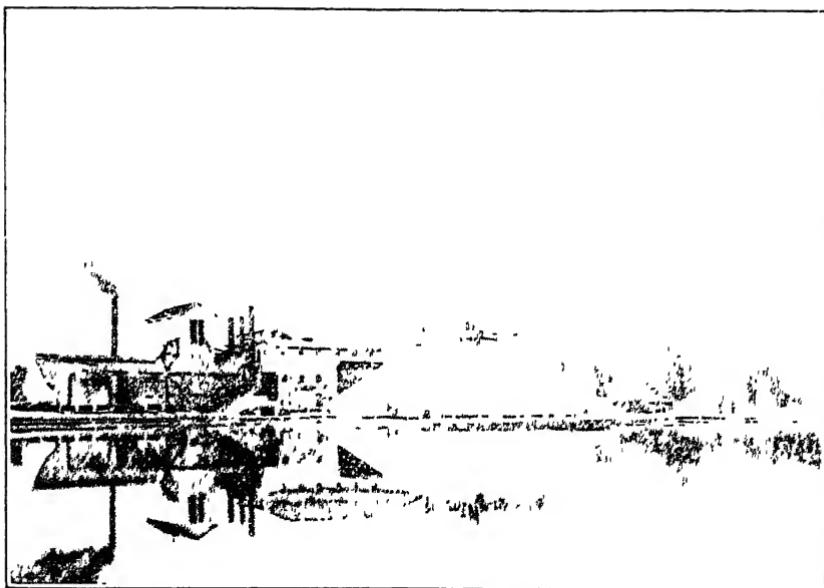
DATA REGARDING SAMPLES.

1. Analyzed by O. D. Allen, Rept. U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 433. Water collected in 1869. A trace of boric acid is also reported in addition to the substances named in the table. Allen also gives analyses of a saline soil from a mud flat near Great Salt Lake. It contained 16.40 per cent of soluble matter much like that of the lake water.
2. Analyzed by Charles Smart. Cited in Resources and Attractions of the Tertiary of Utah, Omaha, 1879. Analyses made in 1877.
3. Analyzed by E. von Cochenhausen, for C. Ochsenius. Zeitschr. Deutsch. geol. Gesell., vol. 34, 1882, p. 359. Sample collected by Ochsenius, April 16, 1879. Ochsenius also gives an analysis of the salt manufactured from the water of Great Salt Lake.
4. Analyzed by J. E. Talmage, Science, vol. 14, 1889, p. 455. Collected in 1889. An analysis of a sample taken in 1885 is also given.
5. Analyzed by E. Waller, School of Mines Quart., vol. 14, 1892, p. 57. A trace of boric acid is also reported.
6. Analyzed by W. Blum. Collected in 1904. Recalculated to 100 per cent. Reported by Talmage in Scottish Geog. Mag., vol. 20, 1904, p. 424. An earlier paper by Talmage on the lake is in the same journal, vol. 17, 1901, p. 617.
7. Analyzed by W. C. Ebaugh and K. Williams, Chem. Ztg., vol. 32, 1908, p. 409. Collected in October, 1907.
8. Analyzed by W. Macfarlane, Science, vol. 32, 1910, p. 568. Collected in February, 1910. A number of other analyses, complete or incomplete, are cited in this paper by Ebaugh and Macfarlane.
9. Analyzed by R. K. Bailey, in the laboratory of the U. S. Geological Survey. Sample collected by H. S. Gale, October 24, 1913.

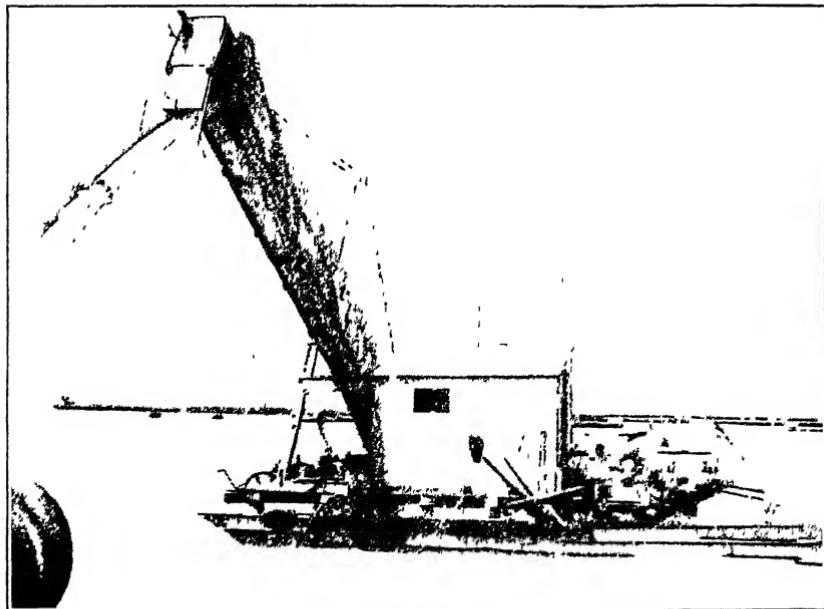
Sodium is higher but calcium and magnesium, especially the former, are distinctly lower in the lake water than in sea water. Carbonates are almost entirely absent from the lake water but are present in ocean water. Calcium carbonate is precipitated on the shore of the lake in the form of oolitic sand. Gilbert^a states that the quantity of sodium chloride in the water of the lake is about 400,000,000 tons and that the amount of sodium sulphate is about 30,000,000 tons.

As the lake is shallow its volume is greatly affected by small changes in its level. As the total salinity (salt content) may be considered fairly constant, the strength of the brines is affected only by the changes in level. Observations were made in 1850, when the lake was at its lowest observed state; in 1873, when the lake was at its highest stage; in 1869, when it was at an intermediate stage; and in 1885 and 1889. From a comparison of the extreme results it appears that the salinity was decreased 39 per cent by a rise of 10.5 feet, which represents on the assumed basis of no change in total saline content an increase of 73 per cent in the volume of water in the lake. The saline matter presumably has been derived chiefly from the fresh-water rivers flowing into it and from the brackish springs along its edges. Whether these springs derive their saline matter from extraneous sources or from beds originally deposited in the Bonneville basin is unknown. If the latter is true the springs

^a Gilbert, G. K., Lake Bonneville. U. S. Geol. Survey Mon. 1. 1890, p. 253.



A LESLIE SALT PLANT, SAN MATEO, CAL



B METHOD OF MECHANICALLY LIFTING SALT FROM THE SALT PONDS AT CALIFORNIA
SALT PLANT, ALVARADO, ALAMEDA COUNTY, CAL

could hardly be regarded as contributing an original quota of saline material. Gilbert^a says that it must be regarded as an open question whether the existing lake and its characteristic brine dates from the end of the Bonneville overflow (Pleistocene) or from a subsequent epoch of extreme aridity.

SALT MAKING AT SALTAIR.

The brine is pumped from the lake into a flume, in which it is carried about 3 miles to the ponds for concentration and crystallization. The ponds are designated from the processes taking place in them as settling ponds, stock or evaporating ponds, and crystallizing or harvesting ponds. They are separated from one another by clay embankments 2 feet wide and 22 inches high, held in place by boards set on edge. Pumping begins in April and continues until the first of September except during storms. Evaporation goes on approximately at the rate of pumping, which is about 5,000 gallons a minute, for 16 hours a day from the middle of June to the middle of September, the season of greatest dryness and hence of maximum evaporation. Pumping is regulated to maintain a constant level in the ponds.

The brine from the lake goes first to the settling ponds, in which it is allowed to remain five or six days to remove all suspended matter. The settling ponds cover about 75 acres. From the settling ponds the brine goes to the stock ponds, which cover an area of about 1 square mile, and it remains in them until concentration reaches complete saturation and salt is ready to deposit, the length of time depending on the weather. The brine then goes to the harvesting ponds. During the summer of 1912, when the writer visited the region, 30 days elapsed between the beginning of pumping operations and the time the brine reached the harvesting ponds. The brine is conducted from one pond to another by gravity, the flow being controlled by small gates.

In the harvesting or crystallizing ponds, as the name suggests, evaporation is permitted till all salt separates. To insure a clean product an under layer or salt floor is allowed to crystallize each year unless it is left over from the operations of the preceding year, as in 1912. When it is left over, as happens when the crop is greater than the market demands, the salt in it becomes more or less dirty and is sold for feeding to stock. The salt that is marketed comes from the upper layer, the plane of demarcation between it and the floor being known as the "split."

The bittern formed in the harvesting ponds is drawn off twice, once at the middle of the season and once at its end. In this way the salt is freed from the bulk of magnesium salts and sodium sulphate. Care must be exercised to draw off the bittern before cold weather

^a Gilbert, G. K., Work quoted, p 258

in order to avoid crystallization of sodium sulphate, which is said to take place when the water reaches a temperature of 20° F.^a Talmage^b believes the critical temperature of the separation to be within a few degrees of the freezing point of fresh water, or approximately 35° F.

Some careful experiments recently carried out in the chemical laboratory of the United States Geological Survey by R. C. Wells have shown that Great Salt Lake water having a specific gravity of 1.145, becomes saturated with respect to mirabilite, $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, at 1° C., or 34° F.

When the bittern has been drawn off the last time and the salt is ready to be lifted, ordinary plows drawn by horses (Pl. X, A) loosen it. Then it is stacked by means of scrapers, wheelbarrows, or hand cars run on tracks in large piles beside the railroad (Pl. X, B). The salt is conveyed in cars from the stacks to the company's mill where it is further refined. Part of the yield is sold without further treatment.

The average crop is about 3 inches of salt, though other writers who have described the industry give figures as high as 6 inches.^c The minimum crop is about 2 and the maximum about 4 inches, though a crop of nearly 5 inches has been obtained.

PRINCIPAL METHODS OF EVAPORATING SALT.

At present the most important methods of manufacturing evaporated salt comprise direct heat and steam evaporation. The vacuum-pan method is included among those in which steam evaporation is employed, although it is sometimes classified separately. Of the various methods of evaporation that have been employed in the past and are now being used, three may be considered, namely, evaporation in open pans, in grainers, and in different forms of vacuum pans. On the following pages these three methods are described in general terms with illustrations of the different steps in the processes from different localities. Detailed descriptions are given of the processes actually used in different States. In this way the reader may obtain an idea of the process without having to go into the details; and anyone who is interested in the details practiced in any particular State can confine his attention to the description given under that State.

DIRECT-HEAT EVAPORATION.

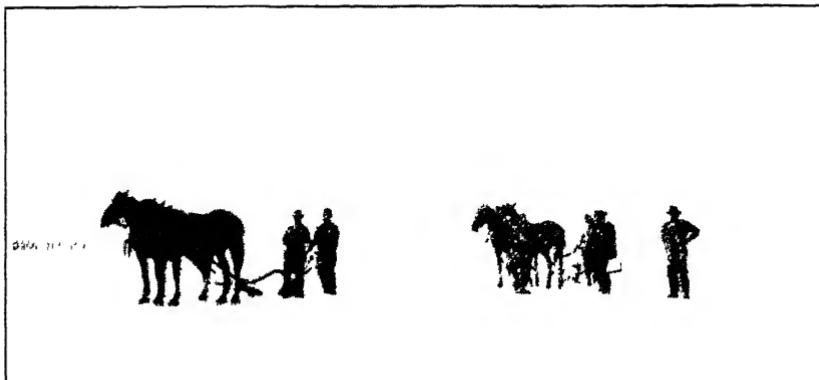
EVAPORATION IN OPEN KETTLES.

HISTORY.

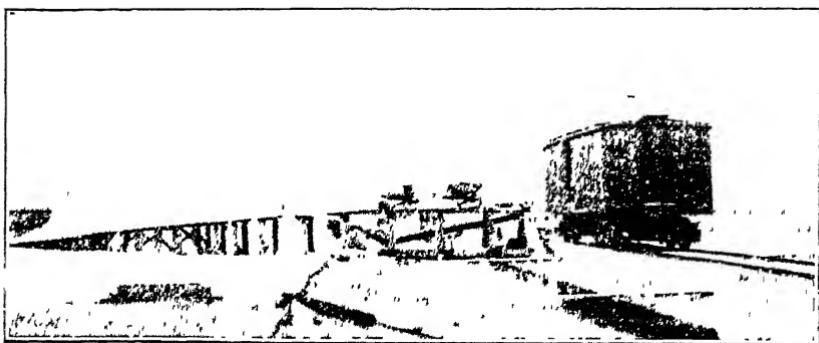
The open-kettle process is the original method employed at Syracuse, N. Y., and so far as known it has been used in recent years

^a Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890, p. 253.

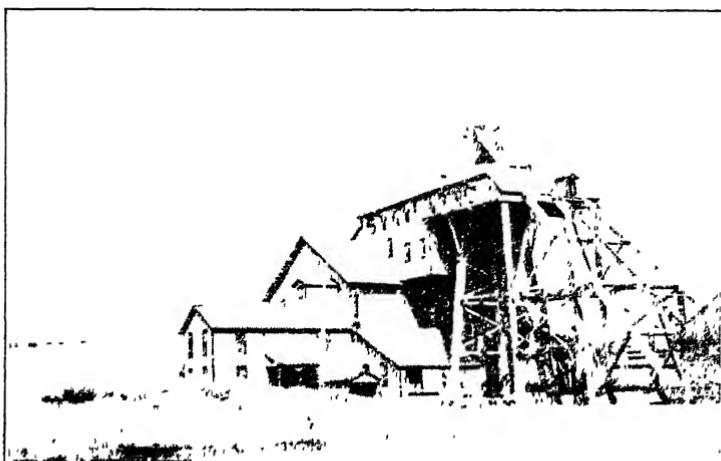
^b Talmage, J. E., The Great Salt Lake—present and past. The Desert News, 1900, p. 80
vol. 92, 1911, pp. 74-75.



A PLOWING SALT IN HARVESTING PONDS, PREPARATORY TO HARVESTING THE SALT
ORDINARY FARM PLOWS ARE USED INLAND CRYSTAL SALT CO., SALTAIR NEAR SALT
LAKE CITY, UTAH



B LOADING SALT ONTO CAR FOR SHIPMENT TO REFINING PLANT INLAND CRYSTAL SALT
CO., SALTAIR, NEAR SALT LAKE CITY, UTAH



C ROYAL SALT PLANT AND REFUSE SALT PILE, KANOPOLIS, ELLSWORTH COUNTY, KANS

only on the Onondaga Salt Reservation. A gradual evolution has taken place from small beginnings dating back to the earliest history of the salt-making industry at Syracuse, when the first salt was made simply by boiling with an open fire. Next a kettle set in an arch of mason work was used, then followed kettles in pairs, and later four kettles combined in a "block," a term still used in the largest salt-making plants in New York and Michigan. The number of kettles in a block gradually increased until 30, 40, 60, and even 100 were placed in a line or in two parallel lines and suspended in two parallel flues or arches terminating in a chimney. As enlarging a block necessitated more fire, the kettles nearest the fire were too intensely heated and arches had to be built under the first 12 or 15 kettles to protect them, a procedure not conducive to economy of fuel. Next, artificial draft was furnished by a pressure blower. Owing to inherent difficulties in the process, it has been estimated that with a given quantity of good fuel not more than two-thirds as much water is evaporated in a kettle block as can be evaporated in a properly constructed boiler. For this and other reasons the kettle system could not compete with other methods and has gradually been abandoned. Originally there were more than 300 salt blocks in the vicinity of Syracuse, but none is now in active use.

CONSTRUCTION OF APPARATUS.

The kettles employed in the process were approximately 2 feet in depth and 4 feet in diameter. Those nearest the fire had a capacity of 150 gallons and those farthest away a capacity of 100 gallons. The kettles were thickest at their bottoms, tapering from $1\frac{1}{2}$ inches to three-fourths inch in thickness at the rim. The lugs or pins on which the kettles were suspended were 5 inches long and $1\frac{1}{2}$ inches in diameter and were placed opposite each other 4 or 5 inches below the rim.

The arches or flues in which the row or rows of kettles were set were inclosed in two side walls, between which when two parallel rows of kettles were used was a central wall built of stone and lined with ordinary brick, except from the front to the fifteenth kettle where fire brick was used. Beyond the grate the fire-brick arches were built with air spaces between them, which increased in size with distance from the grates, thus allowing the heated gases to pass through the spaces without directly striking the bottoms of the kettles. The flues decreased in depth toward the chimney, becoming only 6 or 8 inches deep under the last kettle. The kettles were so hung with their rims against one another, masonry preventing escape of heat between the walls and the kettle rims, that the surface exposed to the heated gases passing through the arches was as large as possible. The slanting of the sides and central walls and the decreasing depth of flue toward the chimney facilitated this.

A wooden conduit lengthwise of the block and a few inches above the central wall had plugs that permitted ready flow of brine to the different kettles by gravity from outside cisterns.

METHODS OF OPERATION.

The brine employed in the manufacture of "boiled" or "common fine" salt, as it was usually called, was of the same strength as that used in the solar process. Before the brine went to the kettles a little quicklime slaked with brine to form a thin milk was stirred in for the purpose of removing the iron, which was quickly precipitated as a reddish-yellow sludge of hydrated ferric oxide. After about 24 hours of settling the brine was a clear bluish-green solution.

When the salt making began a wrought-iron pan so shaped as to fit snugly to the sides was placed in each kettle. The handle of the pan was near the center of the kettle for ease of insertion and withdrawal. It was known as the "bittern pan," and was used to collect the calcium sulphate which began to separate as the brine approached complete saturation. It was withdrawn several times from the kettle before the salt began to separate, and the sediment which collected in it was thrown away. When salt began to form the pan was finally withdrawn. When enough salt had separated it was "drawn" or removed to baskets laid across the rim of the kettle and washed with a mixture of the pickle left in the kettle plus fresh brine added after the removal of the first batch of salt. The basket remained usually until the kettle had been "drawn" a second time, when the contents of the basket were dumped into the bins. The steam from the kettles also acted as an efficient agent in making the salt, as when it rose into the salt in the baskets above it dissolved adhering calcium and magnesium chlorides.

In spite of the efforts to remove calcium sulphate there was a constant tendency for an incrustation to form; this layer thickened more rapidly in the kettles nearer the fire than in those farther away, because salt was made more rapidly in the former than in the latter. The kettles near the fire were drawn every 4 or 5 hours, and those farthest away were drawn only once in 24 or 36 hours. As the layer of calcium sulphate in the front kettles became thicker, it materially retarded evaporation because of its being an exceedingly poor conductor of heat. After five or six days, therefore, the salt was drawn from the front kettles together with nearly all the pickle. Fresh water was added, and after boiling for some time the layer of calcium sulphate was partly dissolved and loosened so as to be easily removed. When the kettles nearest the chimney were ready to be cleaned those nearest the fire had again reached a condition in which recleaning was necessary; the fires were, therefore, allowed to go out, accumulated salt was removed from the kettles, the mother liquor was dipped

out into the gutter, and the kettles were cleaned. Brine was then added and another run was begun, a considerable quantity of salt having formed in the meantime in the front kettles from the heat remaining in the arches below them. This salt was much coarser than the boiled salt and was kept separate. The time consumed in a run varied from 10 days to two weeks. The salt remained in storage for two weeks to drain, after which it was ready for the market.

The quality of the products and the efficiency of the process depended on the weather, on the strength and quality of the raw brine, on the character and condition of the fuel, and on a multitude of other conditions of minor importance.

EVAPORATION IN OPEN PANS.

The open-pan process of making salt is employed in New York, Michigan, Kansas, and on a minor scale in the Sevier Valley, Utah.

PRELIMINARY TREATMENT OF THE BRINE.^a

The brine is pumped from the wells into settling tanks where it remains a day or so exposed to the air to allow the escape of gases, such as hydrogen sulphide, and the precipitation of as much of the iron compounds as possible. Then a thin emulsion of lime is added and the solution is agitated, either mechanically or by hand, or is aerated with a current of air to insure thorough mixing. Through the chemical action of the lime any iron compounds present which would discolor the product are precipitated and removed. A day or so after the addition of the lime, soda ash may be added, particularly if the salt is intended for table or dairy use. After the addition of the soda ash, the brine is allowed to stand for several days to become perfectly clear, but the length of time allowed for settling depends largely on trade conditions. In the Saginaw Valley, Mich., where bromine and calcium chloride are made as well as salt, the bromine may first be removed by electrolysis. The brine may or may not be preheated before it goes to the pans themselves.

PAN CONSTRUCTION AND MANIPULATION.

The shallow open pans employed in making salt are illustrated in figure 1. They are made of riveted wrought-iron plates, $\frac{3}{16}$ to $\frac{1}{2}$ inch thick, and have flaring sides. In New York some that are in use have two compartments separated by a wood or metal partition. These compartments are known as the front and the back pans, the former being nearer the fire. In New York and Kansas the pans are usually about 100 to 115 feet long, 23 to 30 feet wide, and 12 to 18 inches deep, the back or preheating pan being shorter than the front

^a For further details, see "Grainer Process," p. 61.

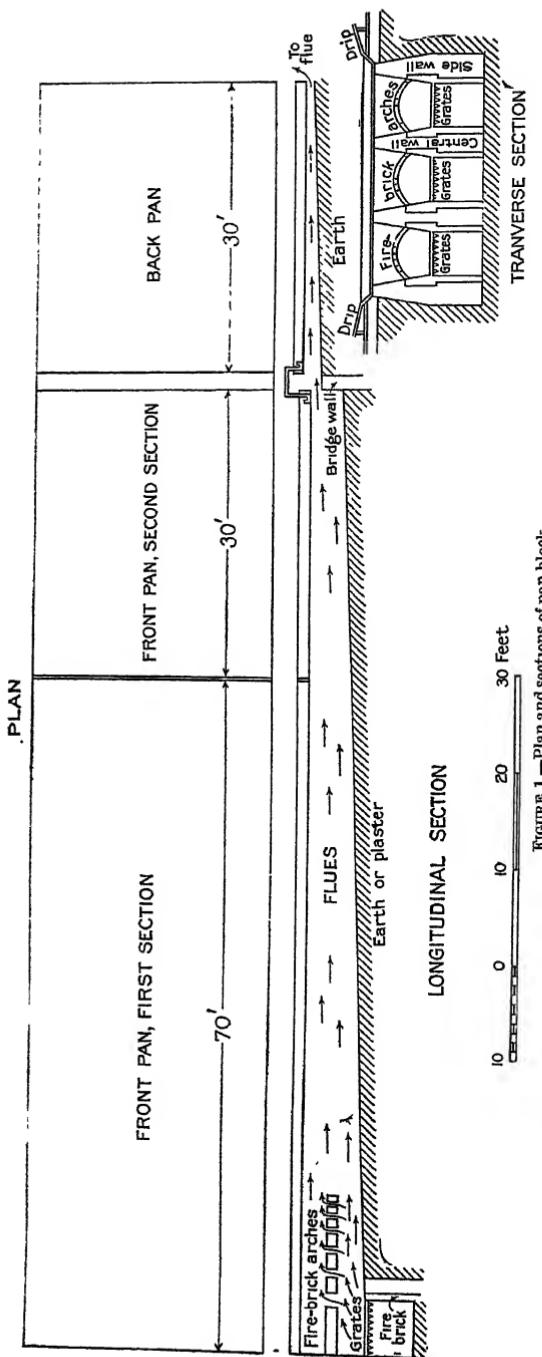


FIGURE 1.—Plan and sections of pan block

pan in which the salt is made. In Michigan the pans are usually not as long or as wide as in New York and Kansas. The brine is first run into the back pan and after being heated by the hot gases from the fires it is siphoned into the front pan. In New York and Kansas the front pan may have two sections, the salt being made in the one nearer the fire, which is usually the longer.

The fuel used in the eastern States is coal, but in Kansas natural gas is employed except in winter when either coal or crude oil may have to be substituted for it. Pans heated by oil or gas differ in details from those heated by coal.

When sufficient salt has separated in the front pan, this salt is removed to the drain board, built along the flaring sides, and allowed to drain there. In the meantime, the front pan is refilled with brine from the back pan which, in turn, is refilled from the settling tanks. Hand rakes are generally used to remove the salt, but in Kansas

some mechanical rakes are used. Mechanical raking is more common, however, in the grainer process.

Modifications of the method of manufacture outlined above and many details connected therewith are described under the different State headings.

CHARACTER OF PRODUCT.

The open-pan process of making salt is employed in New York, Michigan, Kansas, and Utah, and the modes of operation at some works differ materially. The process, though not extensively employed, has its advantages, one of these being the ability to control the grain of the product. To obtain a fine-grained salt, rapidity of crystallization is essential, and this is procured by allowing the brine to boil. Sometimes artificial means are employed, such as the addition of lard, tallow, or butter to the surface of the brine to break up the grain. When salt is made thus rapidly the pans have to be drawn oftener than when coarser-grained salt is being made by the slower process.

PRACTICE IN WYOMING COUNTY, N. Y.

The general operation of the open-pan process is well illustrated by practice in New York. The brine is pumped from the wells into the settling tanks, often during the night to economize time and the use of machinery. After the brine has remained in the settling tanks for 24 hours to allow the escape of hydrogen sulphide and other gases, a thin emulsion of lime is added, and the brine aerated with a current of air to insure thorough mixing. The lime precipitates any iron in the brines. Twenty-four hours after the addition of the lime soda ash may be added, particularly if the salt is to be for table or dairy use. The brine is allowed to stand sometimes seven days in all, but the length of time depends largely on the condition of the trade.

The shallow pans are made of riveted wrought-iron plates three-sixteenths to one-quarter inch thick. The two compartments of a pan are separated by a partition of wood or metal, and are commonly known as the front pan and the back pan. The pans are usually about 115 feet long, including the two compartments, 27 to 30 feet wide, and 18 inches deep. At the plants in New York, where measurements were given to the writer, the back pan was 43 to 48 feet and the front pan 66 to 72 feet long.

The brine, after having been heated in the back pan, is siphoned into the front pan, where crystallization takes place. The ends of the pans are at right angles with the bottom. The sides flare, and upon the drain boards, built out beyond the flaring sides and extend-

is heated by the chimney gases at the base of the chimney. The brine is preheated by the hot flue gases in the back compartment prior to passing to the front.

At one of the plants the brine from the storage tanks passes first into a small double-walled cylindrical tank in the base of the chimney, in which the brine is heated in an annular cylinder 18 inches wide and 20 feet deep, shaped as shown in figure 2. The chimney gases pass out through the central hollow part of the cylinder. It is evident that the preheating part of the pan proper need not be so long where this device is used.

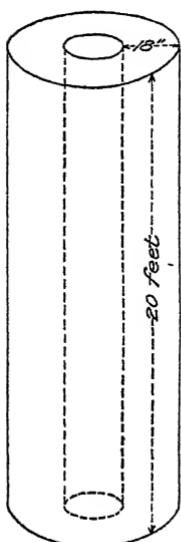


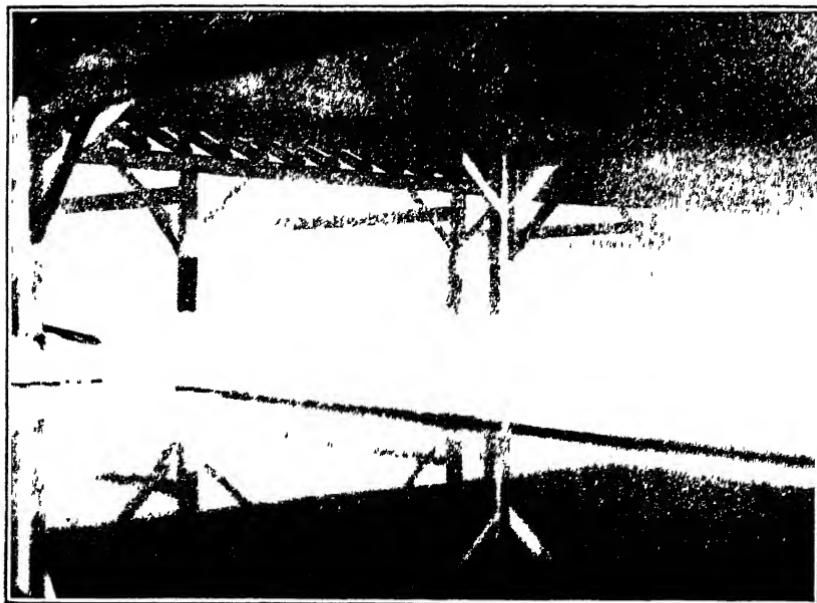
FIGURE 2—Preheating tank for brine at base of chimney

Natural gas is used for fuel except during winter, when coal or crude oil has to be used if the pans are operated. The gas burners are arranged along the sides of the front compartment of the pan, a pan 115 feet long being provided with nine lateral burners on each side of the front section and one main burner in the front. The number of lateral burners used depends on the desired grain of salt. Some of the pans are flared along their sides and provided with drip boards, and in some mechanical rakers move the salt forward to the end of the pan and over an end drip board, though the latter method is more in vogue in the grainer process. The salt is raked onto the lateral drip boards, where these are employed, about every two hours and allowed to drain one hour before being taken to the storage bins.

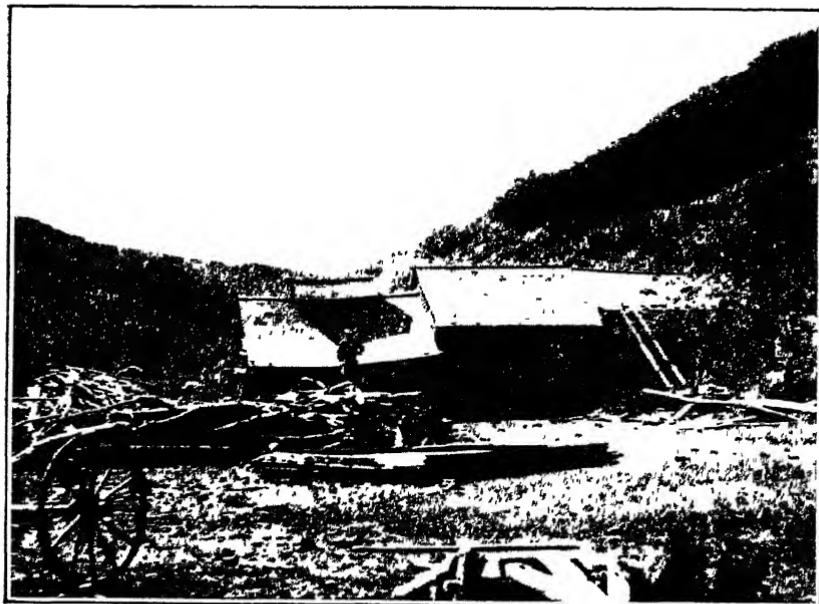
The salt is allowed to remain in bins at least 30 days before being barreled or shipped. The pans have to be scaled every 25 or 30 days, the bittern in them going to waste.

PRACTICE IN SEVIER VALLEY, UTAH.

A small quantity of open-pan salt is made near Redmond, in Sevier Valley, and formerly was made also in Salt Creek Canyon east of Nephi, Utah. (Pl. XI, B.) In the Sevier Valley rock salt from neighboring open-cut mines is the source of the raw material, whereas east of Nephi a brine flowing from a salt spring is utilized. The rock salt in the form of coarse lumps obtained by ordinary mining is dissolved in a small wooden tank outside the plant; the brine thus formed is run into small oblong iron pans, about a foot deep, over wood or coal fires. The brine is boiled vigorously, and as evaporation progresses fresh brine is run in. The salt is raked from the bottoms of the pans at intervals; after it has been dried and ground it is bagged, and at least part of the product is sold for table use.



A OPEN-PAN ROOM, WESTERN SALT WORKS, HUTCHINSON, KANS



B TYPICAL COUNTRY SALT PLANT, 8 MILES EAST OF NEPHI, JUAB COUNTY, UTAH THE
BRINE IS EVAPORATED IN SMALL OPEN PANS

STEAM EVAPORATION.

EVAPORATION IN JACKETED KETTLES.

In past years some salt blocks in the Wyoming Valley, New York, had kettles that were supported in a framework and surrounded by a steam jacket covered with nonconducting material instead of being suspended in a framework of brick or masonry and exposed to the direct heat of the fires as in the open-kettle process. The jacketed kettles could be uniformly heated, and their walls were thin enough for economical transmission of heat. Thus the grain of the product turned out was uniform and the salt itself of good quality. So far as known, no jacketed kettles are now used in New York State.

GRAINER PROCESS.

GENERAL PRINCIPLES OF SALINE DEPOSITION.

If a saturated solution of a salt is concentrated by evaporation, part of the salt is deposited in crystalline form until the solution has again reached equilibrium of saturation. Different salts possess different degrees of solubility, or, in other words, different proportions of them saturate a given volume of water at a given temperature. Therefore, if a solution containing equal amounts of several salts is gradually concentrated by evaporation one salt first reaches its point of saturation and begins to crystallize and form a deposit before the others; subsequently another salt reaches its point of saturation and forms a deposit mixed with more or less of the first salt, which is still being deposited. Finally, after all the water except that retained in the crystals has evaporated there remains a series of deposits, the deposit of the salt that first reached saturation being at the bottom, the most soluble being at the top. If the supernatant liquid is removed before the second salt reaches its point of saturation, the deposit of the first salt is only slightly contaminated by adhering solution and can be rendered very pure by being dissolved in fresh water and recrystallized. This is the principle of the ordinary process of purification by fractional crystallization.

If, on the other hand, more of the original mixed solution is added before the second salt begins to crystallize the concentration of the first salt is decreased less than that of the others, and the deposition of it is thereby retarded less; consequently a thick deposit of the first salt may gradually be formed by continuous evaporation and successive additions of mixed solution, until finally the concentration of the other salts in the solution becomes so great that they also are deposited. This is the principle of separation followed in the grainer process. These fundamental processes, which can be demonstrated in any laboratory, are generally believed to have been those that formed natural saline deposits.

GENERAL CONDITIONS AS TO USE OF WASTE HEAT.

The following information with respect to the general conditions surrounding the use of waste heat is given by Willcox,^a who has had a wide experience.

The low price of salt that has prevailed for several years past and which, according to present indications, will continue for some time to come, has brought forcibly to the attention of salt producers the necessity for economy in the operation of their plants. The low price of salt, the continually increasing cost of labor, and the troubles experienced on account of strikes, etc., have had the effect, first, of introducing labor-saving machinery into salt plants, and second, of awakening the interest of salt producers in the problem of introducing more efficient means for settling and evaporating brine.

Certain arrangements of evaporating apparatus and methods of operating it have grown up as the result of experience in each salt-producing district of the country. Each district, therefore, follows the methods that have been found suited to its individual requirements, and these methods have in the course of time become standard practice for that district. In some sections much study has been given to the problem of brine evaporation, and a voluminous literature has been contributed to the chemistry of salt production. Not so, however, with the engineering side of the problem.

In certain sections, owing to the abundance of cheap fuel and for other reasons, little study has been given to the subject of economical evaporation. In such districts the quantity of output has naturally been the main consideration.

The standard practice in each salt-producing section has been subject to little change or improvement until within the last 10 years, and these changes and improvements have in large measure been necessitated by the low price at which salt has had to be sold.

The manufacture of salt, more especially by the grainer process, is often carried on in conjunction with some other industry. In Michigan, the industry grew up largely as an adjunct of lumbering and is still carried on in connection with it. In other places salt making is related to some local industry. Thus, at Cleveland, Ohio, near Ithaca, N. Y., and at Pomeroy, Ohio, exhaust steam is supplied from the neighboring plants of traction companies, and in one instance the heat for salt making comes from an electric plant of a closely associated mining operation. Advantage had to be taken of the low cost of heat.

In many places heat is employed that otherwise might go to waste, such for example, as that contained in the condenser or tail-water gathered from all parts of a plant, and in a few places economizers are used that utilize the heat of the chimney gases. Such methods are described more in detail under the heading of "Preheating" in the following pages, and under the local discussion by States. To sum up, it may be stated that many salt plants exist simply because of some decisive advantage, one of which is cheap and readily available fuel.

^a Willcox, G. B., Evaporation tests of a salt grainer: Michigan Engineer, 1907, pp. 164-165.

MANIPULATION OF BRINE.

PUMPING.

The brine usually comes from several hundred feet below the surface—in places as much as 2,300 feet. Several methods are used for raising or lifting the brine to the surface; among the more common are there: (1) The air lift or Pohlé system, (2) the hydraulic method, and (3) the old-fashioned sucker-rod and walking-beam pumping system.

In the air-lift system air under pressure is forced down a pipe within the tubing of the well, in which the brine is standing. Rising bubbles of air lift the brine, which is thoroughly aerated—the air escapes as the brine leaves the pipe to enter the first settling tanks. This system of lifting brine is in common use in New York and in certain salt-making districts in Michigan, Ohio, and Texas. Details in applying the method vary in different fields and perhaps in the different plants within the same field.

In certain parts of the Michigan field, brine is also raised by hydraulic pressure; that is, by forcing water into the wells under great pressure, as a result of which the brine is forced out at the same time either from the same or a different well. The water is forced down the outer pipe or casing and the brine flows out of the inner pipe or tubing. In some places underground solution of the salt has progressed so far that the "cavities" of separate wells have merged, and at one plant as many as four "cavities" are known to be connected underground. It is stated by some operators that the method of lifting brine by hydraulic pressure is more satisfactory than by the air-lift method, because a stronger brine is obtained more cheaply and with less destruction of machinery. At some Ohio plants the brine is lifted by the air lift and the air is liberated at the well to avoid jarring the pipes and air compressors. In one plant in Ohio a combination method is employed, the brine being forced to within 800 feet of the surface by hydraulic pressure and the remainder of the distance by means of the air lift. Hydraulic pressure is in use in New York, Michigan, and Kansas. In Kansas the fresh water used in the vicinity of Hutchinson and Sterling is part of the underflow of the Arkansas River and comes from a depth of 30 to 35 feet.

In eastern Ohio, West Virginia, and Pennsylvania, and in certain parts of the Saginaw Valley, the sucker-rod and walking-beam system of pumping has been employed, but modern deep-well pumps are also used at certain plants in these States. The present tendency is toward the complete displacement of the old-fashioned rod and walking beam in favor of the air lift. Along Ohio River the old-fashioned methods have passed into history.

CLARIFYING.

After being pumped to the settling tanks, the brine is allowed to stand long enough to permit the escape of gases—chiefly hydrogen sulphide—considerable quantities of which are present in the brine of certain wells in New York and Michigan; and also to allow the oxidation and precipitation of as much iron as possible. The aeration may also be accomplished, for example, in certain parts of the Saginaw Valley, simply by agitating the brine and allowing it to stand. In plants in the Saginaw Valley, where such preliminary mechanical aeration is carried out, the brine passes directly to the settling tanks, where milk of lime is added, either mechanically or by hand, and the brine is agitated and allowed to stand, sometimes for several days if the storage capacity is exceptionally large.

After standing in contact with the air or after mechanical aeration, brine is treated with milk of lime and thoroughly plunged and mixed, after which it is allowed to stand long enough to settle completely—the length of time depending upon the demand for salt. To remove the excess of lime, soda ash is added at some plants, and the solution is allowed to stand still longer.

In northeastern Ohio milk of lime is added in the storage tanks, but this treatment has not been found necessary in all localities. At one plant milk of lime is forced underground through the casing and thus into the brine. It is claimed that the resulting brine is clearer than usual and that the impurities settle more rapidly, though the reasons for these results are not very clear to the writer. In Kansas the brine as a rule is not treated either with lime or soda ash.

The settling tanks and the preheating tanks vary greatly both in dimension and in construction, and it has been thought wise to give details under the practice in the different States.

PREHEATING

To insure good results the brine is allowed to run into the grainers at the rate at which evaporation takes place and at a temperature slightly below that of the brine in the grainer. The brine is raised to the desired temperature outside of the grainer in preheating tanks. These may be as long and as wide as the grainer, but they are usually deeper and hence of greater capacity. The heat employed is that which might otherwise go to waste, such as that in the condenser or tail water gathered from all parts of the plant, exhaust steam, etc. Whenever there is a surplus of steam, as during the lifting process, direct steam may be employed. Sometimes two sets of preheaters are in use, tail water being employed in the first, and, in the second, to raise the temperature still higher, exhaust steam is used. In rather rare instances what are known as economizers are in use, whereby the heat of the chimney gases is utilized. The economizers

consist of many flues in contact with the brine. As the chimney gases pass through the flues to the chimneys they give up their heat to the brine. In such cases the draft is assisted by a fan.

Because of the peculiarities of practice in southern Ohio and West Virginia, owing to the dilute brine used in those States and also to the industrial conditions differing from those in other salt fields, the general subject of preparing the brines for making the salt by the grainer process is described in detail under the different geographic headings.

OUTLINE OF PROCESS ^a

The grainer or Michigan process of making salt is of American origin. Briefly, it consists in passing live or exhaust steam through metal pipes that are immersed in the brine to be evaporated. The brine is contained in the grainer, a long, narrow, shallow vat built of wood or metal supported on a framework, or of cement or concrete supported on a foundation of sand.

In some districts the process is carried on efficiently, care being taken to conserve the heat wherever possible and to handle the salt as little as practicable. Such plants have usually been able to survive the keen competition everywhere evident in the salt industry. On the other hand, many grainer plants have advanced little during recent years and have steadily decreased their output; some have shut down altogether. Many of the plants exist simply because of some overwhelming advantage, such as cheap and readily available fuel or a market for bromine, calcium chloride, or other by-products.

The output of a grainer varies considerably, depending (1) on whether live or exhaust steam or "tail water" (hot water gathered from different parts of the plant) is used for heat; (2) on its size; and (3) on the general efficiency with which operations are conducted. In those plants where the so-called dividend grainers are used and where the process of making salt is slow the yield is naturally smaller than in plants where exhaust steam is used. The length of time a grainer runs before being cleaned is a variable factor, but great length of time between clean-ups does not signify that the resulting salt is of poor quality, for at some of the grainers it is the aim to have the process a slow one and to make the grain of the product correspondingly coarse.

As the details of the grainer process as carried on in various districts of this country differ markedly they are described by States in so far as such treatment is advantageous, in addition to the general

^a Chatard, T. M., Salt making processes in the United States U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 518-526; Merrill, F. J. H., Salt and gypsum industries of New York. New York State Mus. Bull., vol. 3, No. 11, 1893, pp. 58-60; Wilcox, G. B., Evaporation tests of a salt grainer: Michigan Engineer, 1907, pp. 164-189; Wilcox, G. B., Salt manufacture Trans. Am. Soc. Mech. Engr., vol. 30, 1909, pp. 1065-1085.

descriptions in this place. Many of the statements made, both here and under the State headings, are general, and practice may diverge considerably in individual plants, though all the general statements are based on actual practice.

CONSTRUCTION OF GRAINER.

The grainer may be built of wood, metal, or reinforced concrete. It must remain brine-tight under great differences of temperature. The old wooden grainers, especially in Michigan, were made of white pine, which was then plentiful. The pine grainers withstood the action of the brine splendidly, were easily made, did not shrink much, and when properly caulked with oakum gave good service for about five years. Some of the wooden grainers used are built of hardwood; grainers with sides of beech and bottoms of maple were called to the writer's attention in Michigan in 1911. The reinforced-concrete grainer, a more recent type, is monolithic, has no expansion joints, and is usually provided with mechanical raking devices. It rests on a bed of rammed sand, which gives uniform support and reduces loss of heat by radiation. Its walls are 5 to 7 inches thick and the bottom 4 to 6 inches thick, the reinforcement being $\frac{1}{4}$ -inch steel bars.

The following data regarding a type of mechanically raked grainer (Pl. XII) that is rather widely used in New York, Michigan, Ohio, and Kansas are taken from Willcox.^a Many modifications of the mechanically raked grainer are giving satisfaction

MECHANICAL RAKERS.

During the process of evaporation it is necessary to "lift" the salt that collects on the bottom of the grainer. The salt is lifted either by hand when the grainer is nearly full or automatically as fast as it forms. The automatic method has been generally adopted, because it is less expensive in the long run and obviates the difficulty of procuring laborers to work in the hot steam-laden atmosphere of the grainer room. Various types of salt raker have been developed, their object being to collect the salt and deliver it to the incline or "apron" at the end of the grainer. In whatever manner constructed, mechanical rakers must be capable of keeping clean a floor 100 to 150 feet long and 12 feet wide, and they must deliver the salt to the incline at such rate as will allow it to drain properly before being pushed into the mechanical conveyors for delivery to the warehouse.

Iron or steel rakers are usually used, but these metals are strongly attacked and rapidly deteriorate in a salt-laden atmosphere. Moreover, the iron salts formed by their destruction discolor and thereby cheapen the product. Chains formerly used in the construction of

^aWillcox, G. B., Salt manufacture: Trans Am Soc Mech Engr, vol. 30, 1909, pp. 1065-1085.

salt rakers have been discarded at some plants on account of their liability to break. Wheels also are usually avoided on account of the rapidity with which they wear out in the salty atmosphere. Overhead framework is not desirable because it obstructs the brine surface. For these reasons the most satisfactory automatic rakers are entirely submerged in the brine and are operated by a hydraulic cylinder, placed in front of the grainer beneath the grainer pipes. By this expedient corrosion is reduced to a minimum and no difficulty is experienced from red salt.

The raker (Pl. XII) consists essentially of a framework comprising two steel angles *A* within the grainer near its bottom and adjacent to the side walls. At intervals these two angles are connected by cross braces *B*, and the framework so formed carries a series of feathering scraper blades *C* extending across the grainer and supported at either end on the two side angles by horizontally projecting rocking pivots or fingers, *a*. The scrapers are usually placed about 8 feet apart, and the entire raker has a back-and-forth movement of about 9 feet, so that each blade travels about 1 foot ahead of the initial position of the next blade in front. The salt is thus gradually passed to the front of the grainer and up the incline.

The side angles slide back and forth on a series of flat cast-iron shoes at suitable intervals along the bottom of the grainer. The piston rod of the hydraulic cylinder passes into the grainer through a stuffing box in which are several rings of metallic packing. The cylinder is usually about 8 inches in diameter with a 9-foot stroke. It makes a stroke in about two minutes, bringing up a load of salt every four or five minutes.

BELT CONVEYORS.

On a dry day the salt may be seemingly dry and behave like granulated sugar in the conveyors, but it becomes soggy with increased humidity, and brine will drip from the conveyor on a damp or foggy day. If the conveyor is a belt, the salt on a dry day can be readily cleaned from it by means of a diagonal scraper of plate glass, but on a wet day will stick to the belt, so that removal by any cleaning device is exceedingly difficult. Another difficulty with belt conveyors having iron rollers is excessive corrosion, the underside of the belt becoming covered with iron rust that sooner or later under the sweating of the salt causes rusty water and pieces of discolored salt to drop on the salt piles. A suggested substitute for the iron rollers is an idler made of pepperidge, a kind of wood, about 5 inches in diameter and 2 or 3 inches longer than the width of the belt and having a cold-rolled shaft. The bearings are blocks of well-seasoned maple and ordinary cup grease is used as lubricant. If a conveyor belt is operated continuously for a long time, dirty salt accumulates along the edges and around the rollers at the edges.

ALBERGER PROCESS.

The salient points of the Alberger process, a modification of the grainer process patented by Williams, Alberger & Alberger^a are outlined below.

One of the fundamental essentials of the grainer process is preliminary purification of the brine. Purification from such substances as the sulphate and carbonate of lime is effected by heating the brine in a "purifier" to about 250° to 300° F., thus rendering the impurities insoluble. The purifiers are generally cylindrical, but some are said to be larger at the bottom than at the top, and they are generally made of boiler plate. According to a recent patent, purifiers are partly filled with ordinary gravel about three-quarters of an inch in diameter. The brine under pressure enters the purifier where the impurities are deposited in the gravel and on the internal surface of the purifier. By rotating or agitating the purifier so as to cause the deposition surfaces to rub one another and the interior of the purifier, the impurities are broken away, then they are removed by flushing or any other convenient method.

The grainer used in the Alberger process is a circular evaporating pan, which is filled with brine to a depth of about 1 foot. Attached to its bottom and opening into it at a point on its periphery is a mixer, into which the salt is swept from the bottom of the grainer by arms and scrapers on a revolving shaft. Arms on another shaft sweep the surface of the brine in the grainer and agitate it with "flippers." The arms and scrapers revolve slowly to avoid stirring the contents of the grainer too much and are submerged; the flippers at the surface revolve more rapidly. Brine is fed continuously. The steam pipes in the grainer are supported outside, so as not to interfere with the operation of the rakes.

After having been suitably prepared in the purifier and heated to the proper temperature (226° F.), the hot brine spreads over the surface of the grainer. The flippers strike the salt as it forms in small crystals on the surface of the brine and cause it to fall to the bottom. They also strike a dam or obstruction, so that the salt adhering to them is knocked off. The arms and scrapers revolving slowly aid the circulation of the brine and sweep the salt as it forms from the center to the periphery of the grainer, from which it passes to the mixer and then to the centrifuge, where it is partly dried. If it contains no insoluble matter, it passes to the steam drier and then to the bolters and sifters, where it is finished for the market.

^a Williams, H., Alberger, J. L., and Alberger, L. R., U. S. Patent 400,983, Apr 9, 1889, also U. S. Patent 351,082, Oct. 19, 1886; and U. S. Patent 443,186, Dec. 23, 1890

PRACTICE IN NEW YORK.

The brine, from the well goes to settling tanks (Pl. XIII, *A*). Then, at some plants, it is allowed to stand 24 hours to allow the escape of hydrogen sulphide and other gases. It is then treated with a few buckets of milk of lime and thoroughly plunged, after which it is allowed to stand 1 to 3 days or even longer, the length of time depending on the demand for salt. To remove the excess of lime, soda ash is added at some plants and the solution again allowed to stand 24 hours or longer. To obtain good results the brine is then allowed to run into the grainers at the rate at which evaporation takes place and at a temperature only slightly below that of the brine in the grainer. The brine is raised to this temperature outside the grainers in preheating tanks (Pl. XIII, *B*), which may be as long and as wide as the grainers but are usually deeper and hence of greater capacity. These contain steam pipes placed a foot or so above the floor to heat the cold brine. The exhaust steam from the grainer pipes is the usual source of heat but "tail water"—hot water gathered from other sources throughout the plant—may also be used. Whenever there is a surplus of steam, as during lifting, direct steam may be employed. The preheating tanks are usually in the grainer building and the settling tanks outside.

In New York, grainers 100, 120, 125, 128, and 140 feet long are in use; they are usually 12 feet wide and 20 to 24 inches deep. They are provided with 4 to 8 steam pipes, $2\frac{1}{2}$ to 5 inches in diameter, hung on pendants so that their tops are a foot or less from the bottom of the vat. These pipes are almost as long as the vat and are so arranged that the salt can be raked to the outer side of the grainer.

In grainers in which hand-lifting is employed the salt is shoveled from the grainer to a platform (Pl. XIV) built over and running lengthwise of the middle. Usually salt is removed from such grainers once a day and, after having drained enough is carried in wheelbarrows to the storage bins. In many plants the salt as it forms is continuously moved by mechanical rakers to an inclined plane or "apron" at one end of the grainer, from which the bulk of the adhering bittern flows into the grainer again. Where the salt is removed by mechanical rakes it may fall on a revolving belt, and be conveyed by a bucket elevator to the storage bins without manual labor; or it may be shoved over the end of the apron onto a shelf whence it is removed in wheelbarrows. For best results the brine should be kept at or near the boiling point while the salt is being removed.

To keep the salt at the highest standard particularly if it is intended for table or dairy use, the bittern containing the chlorides of lime and magnesium must be removed every day, every other day, or every third day, depending on the quality of salt that is being made.

As the bittern contains too much salt to be allowed to go to waste it is discharged into another set of grainers known as "dividend" grainers, which are heated by waste or exhaust steam and "tail-water." Because of the low temperature and the consequent slowness of crystallization in these grainers the salt is rather coarse-grained and is used chiefly for meat packing and refrigerating.

Many of the main grainers, from which salt is lifted daily, have to be cleaned and scaled every 3 or 4 weeks, though some are scaled only two or three times a year. The frequency of cleaning depends on the calcium sulphate (gypsum) content of the brine, and large amounts of calcium sulphate are common in the brines of New York.

PRACTICE IN MICHIGAN.

DEVELOPMENT.

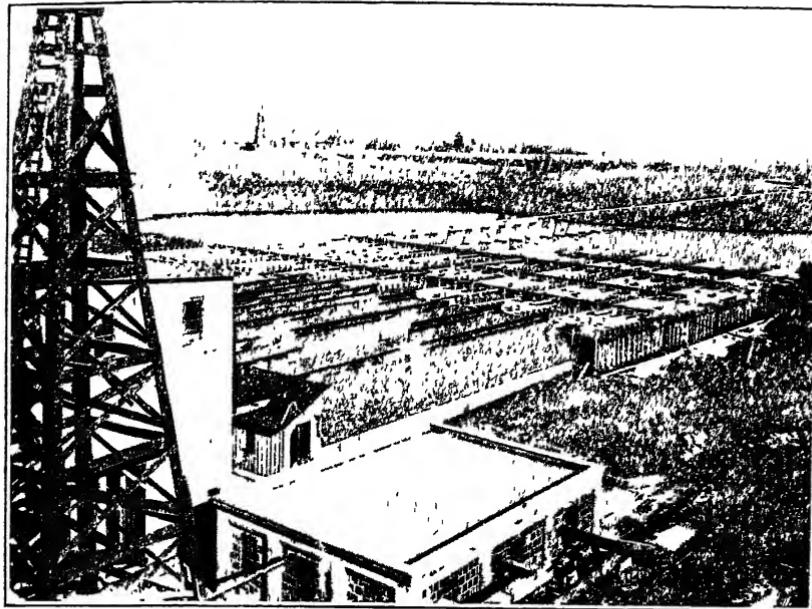
For descriptive purposes Michigan may be divided into three districts as follows: (1) Western part of the Lower Peninsula, including Manistee, East Lake, and Ludington; (2) the Saginaw Valley, including the region about the cities of Saginaw, Bay City, Midland, St. Charles, and Mount Pleasant; and (3) Detroit and to the north and south along St. Clair and Detroit Rivers. The grainer process in this State does not differ in principle from that in New York though it varies in details. Both the grainers from which the salt is lifted by hand and the modern mechanically raked grainers are in use.

Salt making in Michigan was at first only an adjunct of lumbering—refuse lumber and exhaust steam being used for heat. Now the manufacture of salt has become so important as to be an integral part of the business, though it is still a side issue with many firms, and some firms will undoubtedly discontinue making salt as lumbering declines. In general, however, the manufacture of salt in this part of Michigan is so well established that even the decline in the lumber business is not likely to seriously affect it; probably it, like other industries, will adjust itself to changed conditions and will continue to thrive. There will be a change in fuel from wood to coal, and greater economy in utilizing heat.

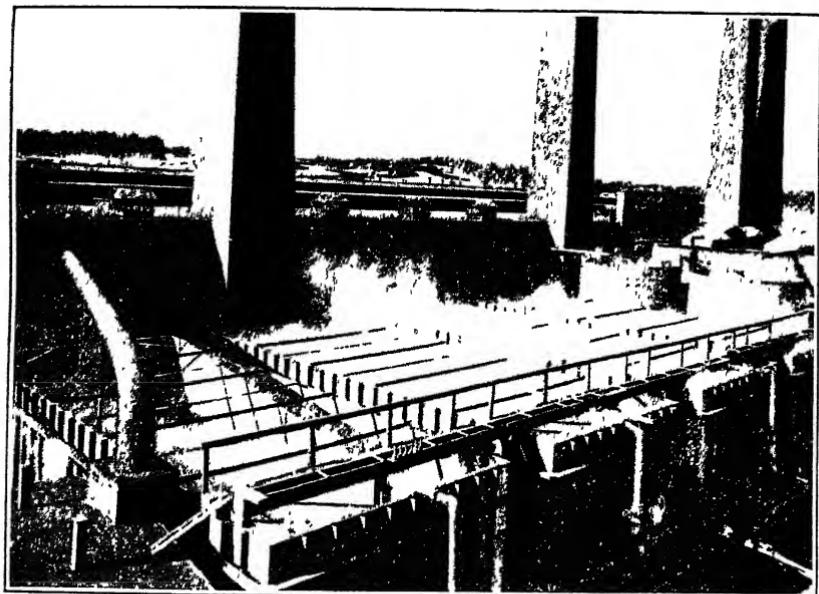
LUDINGTON-MANISTEE DISTRICT.

In the Ludington-Manistee district, which includes Manistee, East Lake, Filer City, and Ludington, more mechanically raked grainers are in operation than those from which the salt is lifted by hand, and at some plants the latter type of grainer serves simply as a complement of the other, utilizing available waste heat and making a coarse salt for which there is good demand.

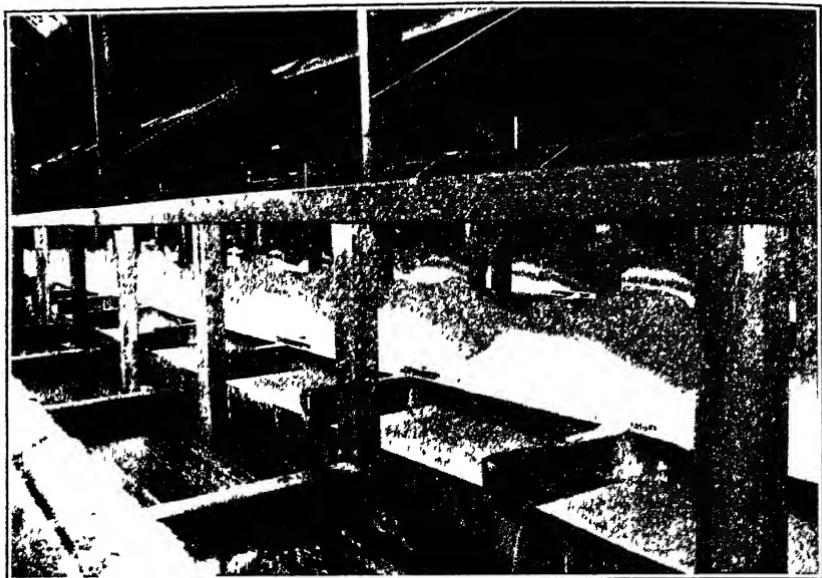
The brine near Manistee is pumped from a depth of approximately 2,000 feet, usually by means of air lifts. The wells at Ludington are reported to be about 2,300 feet deep. The ordinary strength of brine



4. OUTSIDE SETTLING TANKS, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



B. PREHEATING TANKS, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



A GRAINERS IN WHICH SALT IS LIFTED BY HAND, WORCESTER SALT PLANT, SILVER SPRINGS, N. Y.



B GRAINERS AT LIVERPOOL SALT PLANT, HARTFORD, W. VA.

pumped varies from 90° to 100° salimeter. At some of the plants it runs from 98° to 100° continuously if the wells are not crowded; otherwise the strength may decrease to 97° or 95°. At most wells the water that dissolves the salt underground is not pumped into the beds, as in some other fields, but flows in from overlying strata as brine is pumped out; at some wells, however, the water is forced in.

The brine flows from the wells through troughs, or stands in tanks in order to insure elimination of hydrogen sulphide. It then passes through the settling and preheating tanks to the grainers.

The settling tanks in the first set differ greatly in their dimensions. At some plants they are less than 100 feet long, but most of them are 100 to 160 feet long. They are usually 12 to 24 feet wide, a width of 18 feet being common, and are 6 to 8 feet deep. The preheating tanks are 150 to 195 feet long, though one seen by the writer was 300 feet; they are 10 to 15 feet wide, one wider having been noted; and are usually 6 to 8 feet deep. Some are constructed of concrete. These tanks are provided with several 3-inch or 4-inch pipes, through which live steam, tail water, or exhaust steam is passed. So far as the writer is aware, no chemicals are used to prepare the brine for the grainers, though practice may have changed since he visited the field. The brine is heated usually to a temperature of 120° to 160° F., but at some plants, especially those where the brine is weaker than usual, the temperature may rise to 175° F. In places four days are consumed in the passage of the brine from the wells to the grainers.

The grainers are heated more generally by exhaust than by live steam. Where a hand-lifted dividend grainer is a minor part of the establishment, tail water or exhaust steam is generally used to heat it. The grainers are usually 150 to 160 feet long, 10 to 13.5 feet wide, and 18 to 24 inches deep. They are fitted with 6 to 8 and sometimes 9 or even 10 galvanized-iron steam pipes, usually 4 inches in diameter. Some of the grainers in which hand lifting is practiced are shorter than those mentioned, but their width and depth usually fall within the limits given.

The grainers make 60 to 75 barrels of salt in 24 hours, 80 barrels being a maximum. The production depends on so many variable factors that information on this point can not be very definite.

SAGINAW VALLEY DISTRICT.

In the Saginaw Valley district, which includes Saginaw, Bay City, Midland, Mount Pleasant, and St. Charles, brine comes from different depths. In Saginaw the salt wells are 700 to 900 feet deep, at Bay City about 1,000 feet, and at St. Charles 800 feet deep. At Midland the brine-bearing horizon is approximately 1,200 to 1,300 feet below the surface, and at Mount Pleasant the brine supply at one well lies between 1,408 and 1,463 feet below the surface. In places the brine

is somewhat dilute, its salimeter strength varying from 80° to 94°, 100° representing complete saturation with sodium chloride. It is reported that the brine near the center of the basin registers more than 100° salimeter on account of the presence of calcium and magnesium salts, that are more soluble than common salt.

A far greater number of wells were formerly in use in this valley, especially about Saginaw and Bay City. If all wells had been plugged when abandoned, little fresh water would have reached the natural brine, but, according to information received, many of the old wells were not plugged, and consequently the natural brine has been greatly diluted with fresh water from overlying strata. A State law now makes it compulsory to plug all old or abandoned wells.

The brines of the Saginaw Valley, as shown by the analyses given below and those on pages 81 and 82, contain considerable bromine, calcium, and magnesium. The bromine and the calcium chloride, mixed with the magnesium chloride, beside the salt, are obtained at various plants in the district. The brine at the Dow Chemical Co.'s plant, Midland, is reported to contain ammonium, and some of the brines contain ferrous iron, which precipitates as basic ferric salts on exposure to the air and discolors the brine. The specific gravity and the bromine content of the brine increase toward the center of the basin, as the following analyses show:

Analyses of natural brines of Saginaw Valley, Mich.

[Analyst J C Graves, manager Saginaw Chemical Works.]

Constituent.	1	2	3	4
Sodium chloride (NaCl)	11.4	14.7	16.73	0.05
Calcium chloride (CaCl ₂)	do	11.4	8.34	23.70
Magnesium chloride (MgCl ₂)	do	4.2	3.15	9.94
Bromine (Br)	do	.172	.13	.0625
Ferrous chloride (FeCl ₂)	do	.06	.045	Trace.
Calcium sulphate (CaSO ₄)	do	.0104	.005	Trace.
Ammonia (NH ₃)	do	.....	.023	.....
Specific gravity	27.2424 1.238	26.388 1.220	22.0075 1 182	34.04 1.33

1. Brine, Mount Pleasant, Mich.

2. Brine, Midland, Mich.

3. Brine, St. Charles, Mich.

4. Bittern, St. Charles, Mich.

Though details of construction and operation vary widely in the region around Saginaw and Bay City, only a few details of the manipulation prior to evaporation in the grainer call for specific mention. After the brine has been pumped from the well by the old-time sucker-rod and walking-beam system, or by the more modern methods, effort is made to aerate the brine thoroughly in order to oxidize and precipitate as much iron as possible. This is accomplished by plunging the brine; that is, by agitating it and allowing it to stand a given number of hours, say six or more—the longer

the better. In plants where this preliminary aerating is not done the brine passes directly to the settling tanks, in which it is treated with milk of lime added by hand or automatically, agitated, and allowed to stand—usually from 12 to 48 hours. Where the storage capacity is exceptionally large the brine is allowed to stand in the tanks as long as 6 days.

The tanks used to settle the brine differ greatly in size and construction. They are 18 to 39 feet long, 16 to 26 feet wide, and 5 feet to 6 feet 3 inches deep; their capacity ranges from less than 2,000 to nearly 5,500 cubic feet. At the plant of the Saginaw Plate Glass Co. the tanks are 150 feet long, 20 feet wide, and 7½ feet deep, with a content of 22,500 cubic feet, and are constructed of concrete, the favored material in recently built plants.

From the settling tanks the brine passes to the preheating tanks, which are 100 to nearly 200 feet long, 8 to 12 feet wide, and 5 to 6 feet deep. Each tank, according to its size, is provided with 5 to 10 steam pipes, 3.5 to 4 inches in diameter. Exhaust steam or tail water is commonly used to heat the brine, and the solution may be raised to 180° F. or to the temperature at which salt begins to form before it goes to the grainer. This is not the practice at all the plants. At the Saginaw Plate Glass Co.'s plant the brine goes to a second preheater where exhaust steam raises the temperature above that in the first preheater where tail water only is used.

The grainers are 112 to 180 feet long—150 or 160 feet being perhaps the commonest length, 8 to 12 feet wide, and 16 to 20 inches deep. They contain 5 to 8 steam pipes 3 to 3½ inches in diameter. Tallow, corn oil, or some similar substance is used to "cut" the salt crust on the surface of the brine in the grainer. The hand-lifting process and mechanical rakers are both in use.

There is great divergence in the quantity of salt made daily in grainers at different plants, according to the quantity and kind of salt desired, the volume and kind of steam available, and finally whether salt making is considered a vital part of the establishments. Also on the rapidity of manufacture depends the number of times that the pipes have to be scaled, but this also depends on the proportion of gypsum in the brine, which appears to vary more than might naturally be expected. Some firms, of course, may be more economical of heat than others and remove the gypsum from the grainer pipes oftener.

DETROIT DISTRICT.

The Detroit district includes all the salt-making establishments in the southeastern part of the Lower Peninsula of Michigan; that is, those in the suburbs of Detroit, those southward on Detroit River at Del Ray, Ecorse, and Wyandotte, and those north along St. Clair River at Port Huron, St. Clair, and Marine City.

In this district as a whole, the salt-bearing rocks contain more than one salt bed, and at different places brine is obtained from different beds, though in general the salt-bearing rocks lie at progressively increasing depths northwest from Trenton through Detroit, Marine City, St. Clair, and Port Huron.

The brine is raised by air lifts and by forcing. In the latter system the water is forced down the outer pipe or casing and the brine flows out of the inner pipe or tubing. At one plant underground solution of a salt bed has gone so far that as many as four wells communicate freely. Some operators claim that the hydraulic pressure system is more satisfactory than the air-lift system. The brine as pumped is said to be fully saturated at most plants.

Usually the brine is treated in settling tanks with milk of lime. The brine may be "limed" mechanically as it is pumped into the storage tanks or the milk of lime may be added by the old-fashioned hand method. Then the solution is plunged. After treatment with lime, plunging from time to time, and standing several days, the solution goes to the preheating tanks. The settling tanks usually are 30 to 180 or even 200 feet long, 10 to 20 feet wide, and 7 to 9 or 10 feet deep. In capacity they range from little more than 2,500 to more than 25,000 cubic feet. The preheating tanks are generally heated with exhaust steam, but some are heated with condenser water.

Both mechanical and hand-raked grainers are in common use, especially the Willcox type of mechanical raker or a modification of it. Cement-lined wooden or steel grainers are used as well as the regular wooden type. The grainers are 100 to 150 feet long, 12 feet wide, and 20 to 24 inches deep. They are usually equipped with 3½-inch or 4-inch galvanized-iron steam pipes, but those at one plant have ordinary iron pipes coated with whitewash, which does not contaminate the salt by falling off, because it is baked and thoroughly hardened by passing steam through the pipe before salt making starts. Whitewashed pipes shed gypsum more readily in scaling. The grainers at one plant where they are heated with direct steam are V-shaped, being 18 inches wide across the bottom and 12 feet wide across the top. They are 8 feet deep and about 100 feet long. As the salt forms it is scraped from the bottom by an endless-chain raker or hoe and is dumped into a trough by a pushing device like that ordinarily used in the Willcox raker.

PRACTICE IN NORTHEASTERN OHIO.

The centers of salt manufacture in northeastern Ohio are Cleveland, Cuyahoga County; Wadsworth, Medina County; Akron (Kenmore), Summit County; and Rittman, Wayne County. Brines are utilized in the manufacture of soda products, but not of salt, at Barberton, Summit County, and at Fairport Harbor, Lake County.

In this region the hydraulic-pressure method of lifting brine is used. Some operators claim that the method gives a stronger solution and is easier on machinery than the air lift. At some of the plants, however, the brine is raised by air lifts. At one plant a combination method is used, the brine being forced to within 800 feet of the surface by hydraulic pressure and the rest of the way by air lift. The brine as pumped varies in strength from 94° to 100° salimeter, some of the firms aiming to procure brine slightly below complete saturation to avoid the pipes becoming stopped, as sometimes happens in pumping a fully saturated solution.

At some plants the brine is treated with milk of lime in storage tanks but this practice has not been necessary at all places. At one plant the lime is forced into the wells with the water and the resulting brine is said to be much clearer. In addition, lime is added to the brine in the settling tank, but as a result of the preliminary underground treatment the impurities settle more rapidly. The capacity of the settling tanks is 8,000 to 14,500 cubic feet.

As a rule the majority of the grainers at a given plant are worked more rapidly than the rest; usually the rapidly operated grainers are heated by live steam and the slowly operated ones by the exhaust from them, or the rapidly operated grainers are heated by exhaust steam and the others by tail water. Grainers in which the salt is lifted mechanically and those in which it is lifted by hand are in use, but at any given plant the latter are usually fewer and are heated with exhaust steam or tail water. These arrangements are made in order to utilize all available heat and make a grade of salt that is always in demand.

The grainers are made of iron, of iron lined with cement, or of wood lined with cement. Their lengths range from 80 to 150 feet, their widths from 10 to 14 feet, and their depths from 22 to 24 inches.

FORMER PRACTICE AT PITTSBURGH, PA.

The John A. Beck Salt Co., Pittsburgh, Pa., when in existence, used grainers. The natural brine, obtained at a depth of approximately 1,400 feet and raised by sucker-rod pumping, had a specific gravity of 9° B. After the impurities were precipitated by lime in the storage tanks the brine was concentrated in cylindrical boilers at boiling temperature to a specific gravity of 16° B. The brine then flowed by gravity to four settling tanks, in the first of which lime was used. After standing in the settling tanks about four days and being concentrated to a strength of 20° B. (specific gravity 1.16), the brine went to the grainers.

Each grainer was independent of the others; was 140 feet by 9 feet by 18 inches; and was fitted with three 4-inch copper pipes, through which the steam passed. The salt was lifted by hand to a central platform, 150 barrels being lifted from each grainer every 24 hours.

The bittern was utilized in the manufacture of bromine. The grainers were, with a single exception, quick-acting, and the brine actually boiled in them.

PRACTICE IN KANSAS.

Salt is made by the grainer process at Hutchinson, Reno County; Anthony, Harper County; and at Lyons, Rice County; also formerly at Sterling, Rice County; and Ellsworth, Ellsworth County. In Kansas, Hutchinson is the chief center of salt making by evaporative processes, including in this term the open-pan, grainer, and vacuum-pan methods. Some of the plants in Kansas are designed solely for salt making, but others are designed for manufacturing salt in conjunction with other products, such as ice.

In the vicinity of Hutchinson and Sterling the fresh water for dissolving the salt comes from the underflow of Arkansas River. This underflow contains dissolved mineral matter, so that some of the impurities in the bitterns come from it. The water used in dissolving the salt at Ellsworth came from deep wells.

The brine is raised by hydraulic lift, and pumped into the storage tanks. As a rule the brine is not treated with lime or soda ash. Exhaust steam is generally used for preheating the brine before it goes to the grainers.

Grainers of both hand-lift and mechanical-rake types are in use. They are constructed of steel or cement, range in length from 90 to 180 feet, in width from 11 to 14 feet, and in depth from 18 to 20 inches, and are heated with live or exhaust steam. In some plants the grainer pipes are coated with whitewash and heated prior to making salt, thus making the subsequent scaling easier. Grainers are scaled at intervals of 10 to 30 days. At some plants a little butter or oil is used to break the crust of salt as it forms and thus to hasten crystallization. The plants are equipped to burn gas, but crude oil is used when no gas is available.

PRACTICE IN TEXAS.

Several plants, situated at Palestine, Anderson County, and at Grand Saline, Van Zandt County, produce all the salt resulting from the artificial evaporation of brine in Texas.

The rock salt is dissolved underground, and the resulting brine is raised to the surface by air lifts. The brine is treated with milk of lime in the storage tanks. Most of the grainers have mechanical devices for lifting the salt, but hand labor is used at a few. The grainers are built of steel alone or of concrete or cement lined with tile. Lengths range from 75 to 150 feet, but most grainers are 12 feet wide and 22 inches deep, the depth of the brine in them approximating 18 inches. Rakers with chain attachment are used at one plant. Oil is used at some plants to cut the grain of the salt. At Grand Saline the fuel is lignite, obtained 9 miles away, at Alba.

PRACTICE IN WEST VIRGINIA AND SOUTHERN OHIO.

SALT-MAKING CENTERS

Salt is made from natural brines at Malden, Kanawha County, at Mason and Hartford, Mason County, W. Va. and across Ohio River from the latter towns around Pomeroy, Meigs County, Ohio. The peculiar treatment of the brines at these localities deserves special description.

The composition of these brines is shown by analyses 13 to 17 in the table on page 82.

PECULIARITIES OF BRINE

Barium salts are present in the natural brines along the Ohio River. Such salts are not known in appreciable quantities in any other natural brines. These salts are now carefully removed by precipitation with salt cake before the salt-making process begins.^a Also, the Ohio River brines differ from the great majority of, if not all other, natural and artificial brines in being practically free from sulphate of lime. In the evaporation thin copper pipes are used in the different settlers and grainers. Were gypsum present, it would settle on these pipes and they would quickly be ruined by the hammering required to loosen it. The absence of sulphate of lime also is said to account for the salt not hardening.

PRETREATMENT IN MUD SETTLERS

In the vicinity of Mason, W. Va., the wells are approximately 1,100 feet deep, and the brine is pumped by the air-lift method from a depth of 500 to 600 feet. The strength of the brine is 8° B. (specific gravity 1.058 at 60° F.). The brine goes to storage tanks, and from them to the heating tank. This is 70 by 10 by 2 feet and is divided into three compartments, through which the brine mixed with milk of lime is circulated for the purpose of warming and clarifying it. Instead of milk of lime, alum may be used as a precipitant. The brine is not concentrated in the heating tank, and has actually a lower specific gravity on leaving than on entering the tank because of its higher temperature.

The furnace pans are arranged in four batteries or sections, and the brine is heated by means of refuse coal from mines near the plant. The firing is usually done under one section of the furnace pans. Each of the first three sections contains 10 pans bolted together; each pan is 8 feet long and 3 feet wide, with ends less than a foot high, and sides not quite as high as the ends, except that the two end pans have one side as high as the ends of an inside section, these

^a Skinner, W. W., and Baughman, W. F., The removal of barium from brines used in the manufacture of salt. Jour. Ind. and Eng. Chem., vol. 9, Jan., 1917, pp. 18-26.

sides forming the ends of the section. Each section is thus practically a single pan 30 feet long, 8 feet wide, and slightly less than a foot deep, with low transverse partitions. The fourth section is a single pan of the same dimensions, but without transverse partitions. Above the heating pans is a steam chest, and the low-pressure steam from the boiling brine in the pans furnishes the heat for the subsequent evaporating in the mud and draw settlers and in the grainers. Copper pipes convey the brine from one section to another, and log and iron pipes convey the steam from the steam chest to the settlers and the grainers.

The heated brine flows from the furnace pans to three mud settlers, each 130 by 10 by 2.5 feet and provided with two 5-inch copper pipes. The brine runs into one end of the first settler and circulates round a central partition, leaving the first settler with a strength of 16° B. (specific gravity, 1.124).^a In like manner, the brine circulates through the second and third mud settlers, leaving the latter with a strength of 18° B. (specific gravity, 1.142). Alum is added in the first mud settler to help clarify the brine, and a mud or sludge containing iron oxide separates in these settlers.

From the mud settlers the brine goes to two draw settlers, each measuring 130 by 12 by 4 feet and having four 5-inch copper pipes. In general the brine circulates continually through the draw settlers, but can stand in them until it reaches a concentration of 21° to 22° B. At some plants the brine does not pass through both draw settlers but is concentrated in one of them and passes thence to the grainers.

The brine passes through the grainers in succession as the bittern increases in strength. There are seven grainers in series at the plant described. When the salt is ready to be lifted, that in the last grainer, the one farthest from the draw settlers, is lifted first, after the bittern has been removed to the bromine plant. The bittern in the next preceding grainer is allowed to run into the last grainer and the salt in that grainer is then removed, and so on. Then the first grainer is filled from the draw settlers and the operation is repeated. As a result of this procedure the best salt comes from the first grainer and the poorest from the last. Tallow is used to cut the grain of the salt and to hasten granulation. The salt is lifted once in 24 hours, the period of formation being about 18 hours.

The grainers at this plant are of three different types: (1) Cement with tile floor, (2) wood with cement bottoms and tile floor, and (3) wood with tile floors. The grainers usually contain three or four copper pipes 5 inches in diameter. The salt was formerly lifted by hand onto wooden platforms (see Pl. XIV), but it is now mechanically raked. At other plants the grainers have mechanical rakers

^a To convert Baumé degrees to specific gravity the following formula is correct at 60° F: Specific gravity = $\frac{144.3}{144.3 - B.}$ All the specific gravities mentioned subsequently are assumed as at 60° F.

driven by brass chains on brass cog wheels. Where the latter are used each grainer is independent and is thoroughly cleaned about every six days; the bittern goes to a refuse grainer in which it is concentrated to the strength requisite for the bromine plant. The salt made in the refuse grainers is low grade, but finds a market.

PRETREATMENT BY FILTRATION.

The brine from the wells at Pomeroy, Ohio, which has a strength of about 11° B. (specific gravity, 1.083), is pumped into two circular storage vats; then it flows into a heating tank, where it is heated luke-warm by steam from the evaporator. The heating tank is 40 by 8 by 2 feet and is divided into three compartments.

The brine next goes to an inclosed evaporator, where it is boiled and concentrated to 15° B. (specific gravity, 1.125) chiefly by the exhaust steam from the engines, the steam from the boiling brine being used to concentrate the brine in the settlers and grainers. It then goes to a tank, 20 by 6 by 8 feet, from which it is pumped to two filtering tanks. Each of these is 8 feet deep and 15 feet in diameter, and is filled with sand. One is used while the other is being cleaned; and one is cleaned daily. Fresh water is forced upward through the sand. The wash water is wasted.

From the filtering tanks the brine runs to the two mud settlers, which are 90 by 12 by 3 feet and have three 5-inch copper pipes for steam. The brine leaving the second mud settler has a concentration of 18° B. (specific gravity, 1.142), and is concentrated in a third settler to a strength of 19° B. (specific gravity, 1.151). Thence the brine passes to the two draw settlers, which are 160 by 12 by 5 feet and are provided with copper steam pipes. Each of these is independent of the other, and furnishes its own quota of brine at 24° B. (specific gravity, 1.2) to the grainers. There are six grainers, counting the one that contains the bittern for the bromine plant. Salt is made in the grainers for 6 days and at the end of the sixth day each grainer is emptied, the liquor going to the last or bitter-water grainer, in which it is concentrated to 39° B. (specific gravity, 1.37) for the bromine plant. The salt is removed from the grainers mechanically with rakers on an endless chain.

TREATMENT AT MALDEN, W. VA.

At Malden, W. Va., the brine has an average strength of 8° B. (specific gravity, 1.059) as it comes from the wells. It is pumped to a storage tank measuring 50 by 25 by 4 feet, whence it passes to the preheating tank. There it is heated with steam from the evaporators to 160° F. From the preheating tank the brine passes to three evaporators, two of which measure 30 by 12 feet by 14 inches, and the third 45 by 12 feet by 14 inches. Natural gas and slack coal are

the fuels. The brine from the evaporators has a strength of 11° B. (specific gravity, 1.083) at boiling temperature and goes to the mud settlers. The first and second of these measure 160 by 10 by 2 feet and are divided into two compartments, each containing a 5-inch copper pipe. The third and fourth settlers are 160 by 12 by 2 feet and are divided into three compartments, each containing a 5-inch copper pipe. All are made of wood.

The brine leaves the several settlers at concentrations of 15° B. (specific gravity, 1.116) at 150° F., 17° B. (specific gravity, 1.143) at approximately the same temperature, 19° B. (specific gravity, 1.151), and 21° B. (specific gravity, 1.170); then it goes to the draw settler, a cement-lined wooden frame 160 feet long by 12 feet wide by 2.5 feet deep, provided with three 5-inch copper pipes. In it the brine reaches a concentration of 23° B. (specific gravity, 1.190). From the draw settler the brine goes to the five grainers, through which it circulates in series. The salt is lifted by hand. Two of the grainers are built of wood lined with tile, and three are built of cement. Each measures 160 by 10 feet by 18 inches. As the brine passes from one grainer to another its specific gravity gradually increases from 24.5° to 26.5° B. (specific gravity, 1.204 to 1.225) in the first to 32° to 36° B. (specific gravity, 1.284 to 1.332) in the last. From the last grainer the bittern flows to a reservoir to cool before entering the bromine plant.

RECOVERY OF BROMINE.

Where bromine is obtained from bitterns resulting from the manufacture of salt, it may be said to be an adjunct of the grainer process of salt making. For this reason it has been thought best to describe bromine recovery in this place. It must be remembered, however, that a large part of the bromine produced as such or in the form of bromides in the United States is not connected with salt manufacture.

HISTORY.

Bromine manufacture in the United States dates back to approximately the middle of the nineteenth century. U. S. Patent 12077, issued to Amalie Stieren of Natrona, Pa., Dec. 12, 1854, and reissued, describes an "improved process of treating the mother water of salines to obtain useful products." It describes operations for obtaining magnesium sulphate, iodine, and bromine from the bitter water of saline springs.

This patent was followed by others in the sixties issued to persons living at Freeport, Pa., and to persons living at Hartford City, W. Va., Pomeroy, Ohio, 1873; Clifton, W. Va., 1873; Mason City, W. Va., 1875; Allegheny City, now a part of Pittsburgh, Pa., 1887; and Midland, Mich., 1891. Thus the early inventions serve in part as a geographical index of the localities where natural bromine-bearing brines are known in the United States.

PRODUCTION CENTERS.

Bromine is now made in Michigan at Saginaw and St. Charles, Saginaw County; at Bay City, Bay County; at Midland, Midland County; and at Mount Pleasant, Isabella County. At Midland and Mount Pleasant, the bulk of the bromine is not marketed as the element, but in the form of sodium, potassium, ammonium, and other bromides. In the Ohio Valley, bromine is also made at Pomeroy, Meigs County, Ohio, and opposite Pomeroy at Mason and Hartford, Mason County, W. Va. Malden, Kanawha County, on the Kanawha River, a short distance above Charleston, is also the site of a bromine industry. Until within a few years bromine was recovered at Pittsburgh, Pa., but the weakening of the brine stopped the work.

At most of the localities mentioned above, possibly at all except Midland, Mich., bromine is made in connection with the manufacture of salt and calcium chloride. In Ohio, West Virginia, and in the Saginaw Valley outside of Midland and Mount Pleasant, the salt is first removed from the natural brine, and subsequently the bromine and the calcium chloride, the former by chemical means, sulphuric acid and an oxidizing agent being employed. In Midland and Mount Pleasant different methods of manufacture are employed.

Analyses of bromine-bearing brines are shown in the table following:

Results of analyses of natural brines bearing bromine and calcium chloride

[Analyses by W. B. Hicks.]

RADICALS IN PERCENTAGE OF ANHYDROUS RESIDUE

Sample.....	2	3	6a	6b	7	7a	8	9	10	11	12	13	14	15	16	17	
K.....	0.86	1.21	1.19	0.70	0.43	0.28	0.36	0.31	0.44	0.35	0.34	0.30	0.32	0.26			
Na.....	18.99	22.50	13.04	18.42	20.47	29.50	33.46	31.40	21.89	31.38	31.35	41.44	40.73	28.21			
Ca.....	11.51	11.15	17.38	14.14	6.65	3.33	1.19	1.16	1.50	1.41	1.72	1.73	1.45	5.06	6.94		
Mg.....	4.77	2.42	4.11	3.18	1.78	1.64	1.21	1.41	2.72	1.72	1.73	1.45	1.62	1.28	1.70		
Cl.....	62.89	61.64	63.66	62.50	61.24	61.50	61.23	61.42	62.69	61.54	61.76	61.83	61.21	62.31			
Br.....	0.63	0.58	0.58	0.58	0.27	0.25	0.16	0.23	0.52	0.45	0.45	0.41	0.41	0.32	0.52		
SO ₄	0.35	0.41	0.41	0.41	0.27	0.25	0.16	0.23	0.52	0.45	0.45	0.41	0.41	0.32	0.52		
Total solids, by summation.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
Total solids, by titration.....	17.38	23.55	22.61	26.43	18.49	21.37	22.22	25.62	26.87	8.51	9.90	9.88	9.38	7.65			
Specific gravity at 23° C.	17.00	24.01	22.04	26.42	19.40	21.10	22.40	25.60	26.98	8.35	8.82	8.99	8.27	7.49			
.....	1.141	1.194	1.193	1.231	1.143	1.163	1.171	1.222	1.223	1.062	1.062	1.062	1.062	1.062	1.062	1.062	1.057

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF ANHYDROUS RESIDUE

KCl.....	1.64	2.31	1.51	0.62	0.63	0.69	0.39	0.65	0.67	0.65	0.57	0.61	0.50		
NaCl.....	47.03	56.91	32.94	46.33	73.51	75.50	85.14	79.23	55.71	50.04	79.11	80.20	73.27		
CaCl ₂	31.61	30.90	48.16	39.20	18.25	16.92	8.93	14.34	32.65	13.33	13.73	14.04	13.87		
CaSO ₄	18.50	9.21	15.90	12.18	0.23	0.38	0.06	0.04	0.04	0.04	0.06	0.06	0.06		
MgCl ₂	0.72	0.72	0.67	0.78	0.88	0.33	4.71	5.46	10.44	6.85	5.60	4.86	6.41		
MgBr ₂	0.72	0.72	0.67	0.78	0.88	0.33	0.15	0.26	0.60	0.40	0.52	0.50	0.37		
.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

RADICALS IN GRAMS PER LITER

K.....	1.7	3.5	3.2	2.6	0.9	0.7	0.9	0.9	1.1	0.3	0.3	0.3	0.2		
Na.....	37.7	65.1	35.2	55.2	61.9	73.6	87.1	96.8	71.8	28.4	20.8	32.0	22.8		
Ca.....	22.8	31.9	40.9	45.7	13.5	14.0	8.7	16.0	38.8	4.4	4.7	5.4	5.6		
Mg.....	9.5	11.1	10.3	3.7	1.1	3.2	4.3	4.3	8.9	1.4	1.3	1.3	1.4		
Cl.....	124.6	176.9	171.8	202.9	128.7	154.1	159.3	189.2	205.8	55.6	68.4	61.5	50.5		
Br.....	1.3	1.7	1.6	2.2	0.6	0.7	0.7	0.7	1.7	3	4	5	3		
SO ₄	7	7	1	1	1	1	1	1	1	1	1	1	1		
.....	108.3	286.0	269.9	322.9	210.1	249.4	250.2	308.0	328.2	90.4	94.9	106.2	100.4	80.9	

CONVENTIONAL COMBINATIONS IN GRAMS PER LITER

* Blank spaces indicate that a trace of SO_4 was present but not determined

NOTE	—iron, alumina, silica, etc., not determined iron was not looked for	Quantitative tests showed presence or absence in all
2	Ohio Salt Co., Rittman, Ohio	9 Hins Lumber Co., Bay City, Mich
3	Colonial Salt Co., Kenmore, Ohio	11 Midland, Mich
4a	Chas. B. Apple, Lakewood, Ohio	12 Ohio River Salt Co., Mason City, W Va
4b	Chas. B. Apple, Lakewood, Ohio	13 Excelsior Salt Co., Pomeroy, Ohio
5	Seagrove Salt Co., St. Charles, Mich.	14 Pomeroy Salt Association, Pomeroy, Ohio
6	Seagrove Salt Co., St. Charles, Mich.	15 Liverpool Salt & Coal Co., Hartford, W Va
7	Stratford Lumber Co., Well St., Charles, Mich.	16 Liverpool Salt & Coal Co., Stratford, W Va
8		17. J. Q. Dickinson, Malden, W Va

COMMENTS ON THE INDUSTRY.

The usual type of bromine plant, one involving salt wells and salt-making apparatus, has survived in the United States only by virtue of exceptional economic conditions. Cheap coal or other fuel and distance from competing centers have doubtless been factors.

Bromine is made from natural brines that are not of the same purity as the artificial brines, so called, from which salt is made in New York, northern Ohio, and along the Detroit and St. Clair Rivers in Michigan. The natural brines are not so saturated as those obtained by dissolving rock salt, hence they require more heat for evaporation. In places the evaporating apparatus for natural brine has also involved the use of copper and brass instead of iron, which is used in the evaporating equipment for artificial brines. For these reasons and others competition with salt made from rock salt has in the course of years grown more severe, and the salt and bromine industry along the Ohio and Kanawha Rivers and in the Saginaw Valley has steadily diminished.

Without doubt, under the conditions existing before the war in Europe began, there was an oversupply of bromine readily available in the world's market, and prices were so low that certain bromine manufacturers were compelled to store their product to wait for higher prices.

Much bromine is found in connection with the potash salts deposits at Stassfurt, Germany. The bromine is said to occur in the form of brom-carnallite ($MgBr_2KBr \cdot 6H_2O$) isomorphous with ordinary carnallite. Although the German deposits furnish more than half of the world's supply of this commodity, much German bromine has gone to waste and new uses have been urgently sought for it. The sum of \$2,500 has been offered by the Deutsche Bromkonvention Gesellschaft, Leopoldshall-Stassfurt, to the discoverer of a process or compound leading to a new or increased consumption of bromine. The terms of the reward were that the discovery should represent a technical innovation and not adversely affect existing uses of bromine. The process should also lead to a considerable increase in the European consumption of bromine.^a

Bromine manufacture in the United States has undergone many spectacular changes since the European war began. Before the war low prices of bromine had compelled some manufacturers to store their product. When the supply of bromine from Germany, and especially the supply of bromides, was cut off, the domestic facilities could not supply the American demand, and prices soared. In a comparatively short time conditions changed, and this country without doubt can now supply its own requirements.

^a Journal of Industrial and Engineering Chemistry, Wanted: New uses for bromine, vol. 5, September, 1913, p. 780

While the demand was greatest, many new producers entered the field, and as a result there were adjustments in the industry. Now the effects of the larger facilities are being felt. Most of the smaller concerns that entered the industry at the beginning of the war have been well paid, however, for their trouble. Most of the changes in the industry have taken place in the Saginaw Valley, Mich., one of the few important bromine-producing fields in the United States.

One of the readjustments since the war broke out is that of the many plants making salt in the vicinity of Saginaw, Mich.; a few firms only now make bromine. These buy all the mother liquor procurable from the salt concerns that do not utilize it. Thus the manufacture of bromine and calcium chloride from the mother liquor is now carried on at a comparatively few plants and the mother liquors, such as were largely wasted four or five years ago, are now all being utilized.

METHODS OF MAKING BROMINE.

Bromine forms chemical compounds in natural brines, but is present only in small proportion, as the table of analyses on page 82 indicates. In these brines it is always associated with other salts, the principal ones being the chlorides of sodium, magnesium, and calcium. Generally bromine is obtained from the mother liquors that result from the crystallization of salt from brines, but at Midland and Mount Pleasant, Mich., the Dow Chemical Co. extracts bromine from unconcentrated brine.

There are at least three standard methods employed in making bromine. At least two, and possibly the entire three, are now in use in the United States. They are known as (1) the periodic or intermittent process, (2) the continuous process, and (3) the electrolytic process.

PERIODIC OR INTERMITTENT PROCESS.

The periodic or intermittent process of making bromine is in use along the Ohio River in Ohio and West Virginia, at Malden, W. Va., and at Bay City, St. Charles, and Saginaw, Mich. The standard practice along the Ohio River may be taken as typical.

PRODUCTION OF BROMINE IN OHIO AND WEST VIRGINIA BY INTERMITTENT PROCESS.

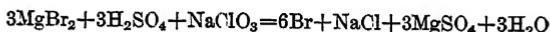
In southern Ohio and West Virginia, after the removal of the bulk of the salt in the main grainer, the bittern in the last grainer is further concentrated to the strength desired for entry to the bromine still—usually to 39° to 41° B. (specific gravity, 1.370 to 1.397 at its highest temperature).

The bromine still is made of sandstone. Though a local sandstone is used at one plant, a sandstone from Buena Vista, near Portsmouth, Ohio, seems to be in general use, and it is said to be practically free

from iron oxide and of close texture, a combination of chemical and physical properties that well adapts it for the purpose. Stills are built in various ways. Some consist of cubical or rectangular blocks hollowed out and placed together edge to edge, so that the hollow parts form a single interior chamber, and some are built up of sandstone rings, 6 inches or more thick, clamped together and cemented with acid-resisting and bromine-resisting material like asbestos or white lead and cotton. The top and bottom slabs are usually the thickest. Holes in the top slab admit the brine and the chemicals. The working capacity of the stills ranges from 400 to 1,200 gallons of liquid.

Sodium chlorate and sulphuric acid of 66° B. are used in liberating the bromine from the bittern. Formerly manganese dioxide and sulphuric acid were used and later potassium chlorate and sulphuric acid. Comparison of the molecular weights of potassium chlorate (123) and sodium chlorate (107) shows that the latter compound is a more efficient oxidizing agent than the former, weight for weight, without reference to the lower price of the sodium compound, which is now used almost exclusively. Some firms use 60° sulphuric acid, which costs less than the 66° acid. The readiness, however, with which the more dilute acid attacks iron, especially the iron tanks used to transport it, has caused the more concentrated acid to displace it almost completely.

After the bittern enters the still and the requisite amounts of sodium chlorate and sulphuric acid are added, a jet of steam is discharged into the solution. As the temperature rises, a reaction, approximately represented by the following equation, takes place:



The bromine set free passes from the still as a gas. But the reactions are more complex than the equation indicates, for some chlorine is liberated and passes from the still with the bromine. The latter is freed from chlorine by passing through washers filled with milk of lime $[\text{Ca}(\text{OH})_2]$, which forms, with the chlorine, calcium chloride (CaCl_2) and calcium hypochlorite $[\text{Ca}(\text{OCl})_2]$. Some bromine is taken up by the lime but is recovered later. The bromine distilled goes to a condenser. This is a rectangular box about 5 feet long, through which three lead pipes extend from the still to three glass collecting bottles in series, sealed to one another and to the worm with mud or clay. Any bromine that passes the last bottle is caught in towers 6 to 8 feet high and 2 or 2.5 feet in diameter made of sewer pipe and filled with coke. Any bromine water that collects in them runs out at their base. The bromine caught beyond the first bottle is usually rather dilute, and may be returned for further distillation. About 35 pounds of bromine is obtained from 700 gallons of bittern.

having a strength of 40° B. The amounts of sodium chlorate and sulphuric acid necessary depend largely on the concentration of the bittern.

DISTILLATION OF BROMINE IN MICHIGAN.^a

The old practice in Michigan did not differ fundamentally from that described above. After the bulk of the salt has been removed in the grainers, the bittern or mother liquor containing the more soluble salts in the form of calcium and magnesium chlorides, bromides, and iodides is run into other tanks or grainers, where it is further concentrated to a specific gravity of 30° or 31° B. Of course, salt separates in these grainers, after which the liquor is ready for the bromine stills.

The boiling bittern is run into sandstone stills having a capacity of 400 to 1,000 gallons, and treated with dilute sulphuric acid and sodium or potassium chlorate, which produces free chlorine, which in turn liberates the bromine from its combinations.

Formerly manganese dioxide was used in the place of chlorate, as was also true along the Ohio River, but it has been discarded for economy and ease of handling. Most of the Michigan makers of bromine in recent years have employed sodium chlorate instead of potassium chlorate for the reason already given—its producing more bromine per pound.

The bittern in the still is kept boiling by the continuous inflow of steam, and the bromine is blown out by the same means. The bromine vapor and water coming from the still are condensed in lead pipes running through cold water contained in a rectangular box 5 to 6 feet long and 3 feet deep.

The lead condenser has always been objectionable, as it requires frequent renewal at considerable expense. The writer was told that the lead coils are serviceable for 30 to 50 runs. Provided a still holds 500 gallons per run, a lead coil would serve at the maximum for distillation of fifty times 500 gallons, or 25,000 gallons of liquid. The bromine made in such lead coils, moreover, is apt to be contaminated, as the bromine attacks lead. There has been a tendency to replace lead coils with hollow earthenware disks and coils of the same material. These work perfectly and tend to preserve the purity of the bromine. They are somewhat fragile, and those that are of foreign make are not readily procurable, especially at present (1916). The lead coils in common use are not nearly as long as the earthenware coil, but this drawback appears not to be insurmountable. Lead worms seen by the writer were 16 feet long, whereas the earthenware worms were 40 feet.

The bromine is collected in stoneware receivers and is separated from the accompanying water. If it is not up to the standard of the

^aDiehl, O. C., The technology of bromine: Mineral Industry during 1908, vol. 17, 1909, pp. 92-94.

United States Pharmacopœa, which calls for 97.6 per cent bromine, it has to be brought up to this standard by any proper means. It is marketed in bottles holding 6½ pounds. The process outlined above is not in use either at Midland or Mount Pleasant, according to the writer's present information.

DRAWBACKS TO PERIODIC PROCESS.

According to the common chemical method of making bromine, described above, the mother liquor or bittern obtained from concentrating the natural brine and removing the salt from it, is boiled with an acid and oxidizing agent to liberate the bromine. The bromine and steam are then condensed, and the former separates by virtue of its specific gravity and its insolubility in water.

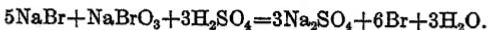
This method of bromine manufacture is costly because of the great volume and weight of the solution from which the desired end product is distilled. Moreover, large apparatus is required to handle the liquor and considerable heat for distillation. Other drawbacks to the chemical method are loss of time and materials and a rather low efficiency, the recovery of the bromine present in the original brine from the mother liquor being only 60 per cent.

RECENT DEVELOPMENTS IN PREPARING BROMINE.

Recent patents outline methods of preparing bromine by oxidation reactions similar to those employed in the ordinary chemical processes that have been described. However, the methods of producing the original bromides or bromates are not given, but they may be made by the continuous process subsequently described.

Barstow ^a has devised a process in which the liberated bromine is separated by gravity from the accompanying solution. A strong solution of the bromide and bromate is made up, sodium bromide and either sodium or potassium bromate being usually employed.

The bromide and bromate are generally used in proportions of 5 of the former to 1 of the latter, as indicated in the reaction below. The prepared solution is run into a cement-lined tub having a cement-covered agitator and a lead worm. Sulphuric acid is added slowly; the solution is agitated and the temperature is kept low by means of the cooling coil, but above the crystallizing point of the sodium sulphate formed. Enough acid is added to combine with the bases present, as indicated by the reaction.



The bromine precipitates as a heavy liquid which is only slightly soluble in the strong sulphate solution. After all the acid required

^a Barstow, E. O., U. S. Patent No. 1141922, June 8, 1915, assigned to the Dow Chemical Co., of Midland, Mich.

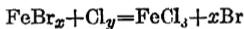
has been added, the solution is cooled substantially to the crystallizing point of the sulphate. The bromine collects on the bottom of the container and may be drawn off from beneath the sulphate solution. It has been found that where sodium bromide, sodium bromate, and sulphuric acid are used, about 95 per cent of the bromine in the bromide and bromate may be drawn off as liquid bromine, only a small quantity remaining dissolved in the sulphate solution. The traces of bromine that remain in the solution may be recovered, if desired, by blowing them out with a current of air and absorbing them in an alkali solution.

It is thus possible to obtain the desired product, namely, liquid bromine, as a direct result of a single reaction involved in the process. This is accomplished without any wasteful expenditure of heat, in the form of steam, and at the same time it does away with the necessity for handling hot bromine vapors, which are both corrosive and very unpleasant to deal with.

Barstow ^a has devised another and different process of preparing bromine.

In this process a strong iron bromide solution is used, and obviously, the bromine occurring in the natural brines, magnesium bromide, sodium bromide, etc., must be converted into iron bromide by any of the usual methods before the process may be employed.

Figure 3 shows a diagram of the apparatus. The strong iron bromide solution is fed into the top of a tailings tower, 1, the solution being supplied from a tank, 2. After descending through the tailings column the solution passes through a condensing coil, 3, thence through a reaction column, 4, in which it meets a rising stream of chlorine gas supplied from a gas main, 5. The chlorine reacts with the iron bromide, forming iron chloride and liquid bromine in accordance with the following reaction, in which the values of x and y vary with the relative proportions of FeBr_2 and FeBr_3 in the iron bromide solution:



A strong iron chloride solution and liquid bromine are thus produced, the latter being only sparingly soluble in the former. Some heat is generated in the reaction, which may vaporize part of the bromine, but the bromine vapors will be condensed in the condenser 3 and flow back into the column 4. If a small quantity of bromine vapor be carried through by the air that may be intermingled with the chlorine, it will be absorbed in the tailings tower 1 by the fresh iron bromide solution entering from tank 2, as such solution usually contains some ferrous bromide, for the reason that the strong ferric bromide solution is a good mechanical absorber of bromine, and the

^a Barstow, E. O., U. S. Patent No. 1141921, June 8, 1915, assigned to the Dow Chemical Co., of Midland, Mich.

ferrous bromide present is an active chemical absorbent. The bromine is thus kept from escaping from the system, and any air fed into the reaction column with the chlorine escapes through the

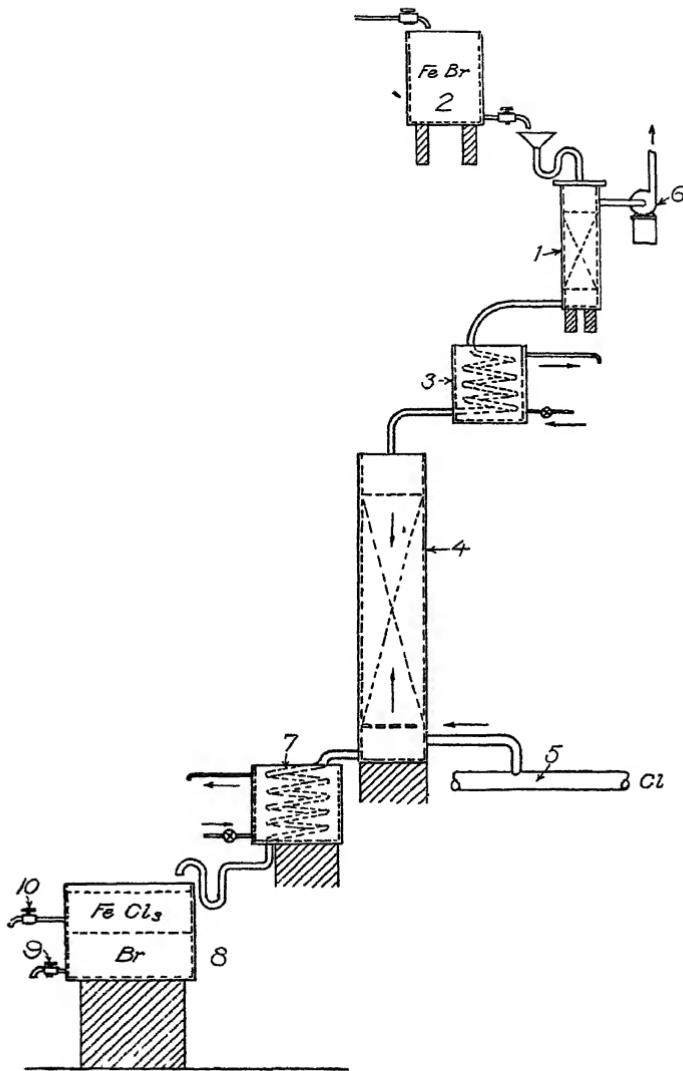


FIGURE 3.—Apparatus for producing and separating bromine without distillation

exhauster 6 that maintains the flow of chlorine upwardly through the reaction column 4. The mixture of strong iron chloride and liquid bromine flows downward through the reaction column and from it through a cooling worm 7 to a container 8, where the bromine sepa-

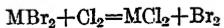
rates by gravity from the iron chloride solution. On account of the greater specific gravity of the bromine it sinks to the bottom, and the separation of the two liquids is sufficiently perfect to make it possible to draw them off by two separate spigots 9 and 10. The bromine obtained usually contains considerable chlorine, which is removed by agitation with a bromide solution, preferably iron bromide, such as is used in the principal reaction. A small part of the bromine, moreover, will remain dissolved in the iron chloride solution, but this may be removed, if desired, by throwing it out with a blast of air and absorbing it in any suitable way, for example, with a solution of ferrous bromide.

The process described does not require any steam and obviates handling hot bromine vapors, which are both corrosive and unpleasant to deal with. When a sufficiently strong solution of iron bromide is used it has the further advantage of producing a solution of iron chloride with a specific gravity of 35° B., or more, which is an article of commerce. If the bromine were separated by the usual processes of injecting live steam, the chloride solution would be so dilute as to require concentration before becoming available for sale or for ordinary commercial use.

CONTINUOUS PROCESS.

The disadvantages outlined under the intermittent method of making bromine have led to the adoption of what is usually known as the continuous process, a chemical as contrasted with the electrolytic method, in which the electric current sets free the bromine. In the continuous process chlorine gas is the agent used to liberate the bromine from its combinations, and the chlorine may be made by any convenient means, for example, by electrolysis of a pure or impure sodium chloride solution, or by combining such chemical compounds as will produce chlorine, for example, bleaching powder and sulphuric acid.

The chlorine gas that is produced in standard cells of different types, or by other means, is passed through the bromine-bearing brine. The bromine is liberated according to the simple reaction



in which M stands for metal, leaving the bromine mechanically held in the solution. The bromine is recovered from its solution in the brine by air currents brought into contact with it. The bromine-laden air is then brought into contact with such substances as will readily form a chemical combination with it. Iron may be used, a solution of ferric bromide being formed. If a solid is desired, ferrous bromide may be made from the ferric salt by suitable means.

A remarkable series of patents have been taken out by Herbert H. Dow, of the Dow Chemical Co., of Midland, Mich., relating to the preparation of bromine by the continuous process.

The series of patents begins with one describing a "process of extracting bromine," No. 460370, dated September 29, 1891, and a reissue patent No. 11232, dated April 12, 1892, with the same title. These two patents will be briefly outlined.

Many salt wells, especially in Saginaw Valley, will not pay when worked for salt alone, owing to the low price for that commodity. When the brine from such salt wells is rich in bromine, it is of considerable commercial importance to be able to extract it cheaply without incurring the expense of evaporating the brine. The process described, however, is applicable to bitter waters after the salt has been removed from them.

Electricity, chlorine gas, or a combination of compounds that will produce chlorine gas, for example, bleaching powder and sulphuric acid, may be employed to liberate the bromine left in solution in the brine.

The bromine is recovered after liberation from the brine by air currents which drive it out. The bromine-laden air is then brought into contact with any substance that will chemically combine with the bromine, for example, iron turnings or filings. Ferric bromide forms, which with the moisture absorbed from the air forms a solution. If a solid is desired, ferrous bromide (which is a more stable compound when heated) may be formed by bringing the solution of ferric bromide into contact with iron and evaporating to dryness in a vessel from which air is excluded by steam. Other metals may be substituted for iron when other bromides are desired, and other gases, for example natural or artificial gas, may be substituted for air for driving the bromine from its solutions.

The brine may be treated electrolytically in tanks or chlorine may be forced through it, either in the form of a gas as such or the chlorine may be formed by the interreaction between bleaching powder and sulphuric acid in the brine itself. The brine containing the bromine is drawn off into shallow tanks placed near the upper part of a closed space or room. The tanks are provided with a series of drip holes from which the brine showers down on sheets of burlap stretched on frames in an inclined position. Wooden surfaces may be used instead of the burlap. A blower sucks air through the descending solution containing the bromine in such a way that fresh air comes in contact with the solution most depleted of its bromine. Thus all the bromine is removed from the solution, and the air as it passes on comes in contact with brine richer and richer in bromine. The air passes off through a duct, then through the bottom of a container which is partly filled with iron turnings or scrap iron, with which the

bromine unites to form ferric bromide. With the moisture there is formed a solution of the ferric bromide, which drops through a spout into a suitable stone container. The air from which the bromine is freed is again used, and so the process goes on. The lower floor of the apparatus is inclined so that the spent brine flows away through a trap and no air is wasted.

These first patents were followed by others, which involve modifications and improvements, or relate to closely allied operations, such as the manufacture of bromides. Later patents are as follows:

Process of extracting bromine from brine; No 714160, November 25, 1902, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromine, No. 733466, July 14, 1903, issued to Herbert H. Dow.

Process of manufacturing bromides from bromine-containing solutions. No. 733467, July 14, 1903, issued to Herbert H. Dow.

Process of extracting bromine from brine, No. 741637, October 20, 1903, issued to Herbert H. Dow, of Midland, Mich., assignor to the Dow Chemical Co., of Midland, Mich.

Process of fractioning bromine apart from chlorine, No. 752286, February 16, 1904, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of fractioning bromine from chlorine, No. 752331, February 16, 1904, issued to Herbert H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromine from natural brines, No. 752332, February 16, 1904, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Method of converting bromine into bromides and bromates; No. 765417, July 19, 1904, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Process of manufacturing bromides, No. 997972, July 18, 1911, issued to H. H. Dow, assignor to the Dow Chemical Co., of Midland, Mich.

Other patents relating to the preparation of bromine or halogen compounds, among which bromides are included, are as follows:

Method of making haloids, No. 964156, July 12, 1910, issued to James C. Graves and John P. Simons, assignors to the Dow Chemical Co., of Midland, Mich.

Method of making halogens, No. 1036121, August 20, 1912, issued to Coulter W. Jones and Arthur E. Schaefer, assignors to the Dow Chemical Co., of Midland, Mich.

Process for the recovery of bromine, No. 1085944, February 3, 1914, issued to Arthur E. Schaefer, of Saginaw, Mich.

Method of extracting bromine; No. 1188838, June 27, 1916, issued to Arthur E. Schaefer, assignor to the Dow Chemical Co., of Midland, Mich.

In this connection, two patent specifications issued to Herbert H. Dow and relating to electrolytic cells are of interest. These are as follows:

Porous diaphragm for electrolytic cells and method of producing same; No. 621908, March 28, 1899.

Method of and apparatus for electrolyzing liquids, No. 1100290, June 16, 1914.

ELECTROLYTIC PROCESS.

The electrolytic process for making bromide depends on the principle that bromides decompose at a lower voltage than chlorides and

hence are first decomposed by the electric current. Notwithstanding that the reaction is carried only far enough to liberate the larger part of the bromine, it always results in the production of some chlorine which subsequently has to be eliminated. Diaphragm cells may or may not be used. A weak current is used—not more than 4 to 5 volts. It is not known whether the process is used in the United States, but it probably is. Owing to the low concentration in bromides and the large bulk of liquor generally handled, and also to the formation of bromates and chlorates, the efficiency is low.

One method of carrying on the process is as follows. The brine is run into long wide wooden vats in which carbon electrodes are introduced and in which the electrolysis takes place. The solution containing the bromine trickles continuously over a lattice work down a tall wooden tower, upward through which passes a strong air current. The bromine vapor is then passed through water and an aqueous solution is formed. The aqueous solution then trickles downward through another tower built of bromine-resisting material such as sewer pipe. In this tower are coils of thin iron ribbon or wire. The iron combines with the bromine, forming bromide of iron. This compound is next treated with sodium, potassium, or ammonium hydroxide, depending upon the bromide desired. This mixture is boiled down in cylindrical iron tanks, and after the reaction is completed the precipitated ferric hydrate is filtered off and the clear solution further concentrated until the bromides crystallize out. These are dried over steam coils or in any other suitable manner.

According to Blount and Bloxam,^a "Bromine is now also obtained from the Stassfurt residues by electrolyzing the liquors between carbon electrodes in open vessels, through which the liquid is passed at a certain rate. Up to 30 secondary carbon electrodes are placed in the vats, which practice permits a current of 90 volts to be used. This is found to give the maximum efficiency. The bromine liberated remains dissolved as such in the liquid and is separated at a subsequent distillation.

"The crude bromine contains chloride of bromine and generally lead bromide and hydrocarbons, the latter being derived from tar joints. It is shaken with potassium bromide to decompose the bromine chloride, and distilled in glass retorts."

USES OF BROMINE.

Bromine is used in the manufacture of certain coal-tar dyes such as the brom eosins, also in the manufacture of such bromides as potassium bromide, sodium bromide, ammonium bromide, and strontium

^a Blount, B., and Bloxam, A. G., Chemistry for Engineers and Manufacturers, 1910, p. 459.

bromide. It is also used as a reagent in analytical chemistry and in the manufacture of certain organic bromides. The latter are used in photography and in medicine.

Bromine has also been used in extracting gold from its ores and in refining platinum, and in connection with the manufacture of Prussian blue and potassium permanganate. It is also a disinfectant. It is reported to have been used in the present war in the asphyxiating mixtures used in the trenches, its effects being reported to be most disastrous, and burns from bromine severe.

It is considered dangerous freight by the transportation companies, and it sometimes appears in the form of "solidified bromine," patented by Frank. This consists of sticks of diatomaceous earth made plastic with size or molasses and then pressed into sticks of $\frac{1}{4}$ -inch or $\frac{1}{2}$ -inch diameter, which are dried or burned till coherent, but not to the degree of losing their porosity. They are then soaked in liquid bromine contained in wide-mouthed, stoppered, glass bottles. The porous material absorbs 50 to 75 per cent of its weight of bromine, after which the excess liquid bromine is poured off. The sticks are sold in the same bottles. Bromine in this form may be used conveniently as a certain number of sticks represent a given weight of the substance, and the necessity for weighing the liquid itself is thus obviated.

RECOVERY OF CALCIUM CHLORIDE.

Under this heading is considered only calcium chloride that is produced in connection with the manufacture of salt and bromine from natural brines. The waste calcium chloride so largely produced in connection with the ammonia soda process at Solvay, N. Y.; Wyandotte, Mich.; Barberton and Fairport Harbor, Ohio; Hutchinson, Kans.; and Saltville, Va., is not considered, for such calcium chloride derives its base from limestone and its acid from common salt, and it is not, as such, an original constituent of the brine.

OHIO AND WEST VIRGINIA.

In the chemical process of making bromine the bittern from the bromine stills goes directly to the calcium chloride plant. Here it is generally first neutralized with lime and allowed to settle as long as necessary; it may go to a rectangular vat for further concentration. After having settled it is run to the kettles for final evaporation. The kettles are cylindrical with conical bases fitted with steam coils; some also being provided with steam jackets through which live steam is passed. The liquor is boiled in them to the consistency of a thick sirup. A plug is then drawn from the bottom of the kettle

and the thick liquid is run into metallic drums, in which it solidifies on cooling. It is then ready for market.

Analyses of the brines are shown in the table on page 82.

MICHIGAN.

When bromine is not recovered from the mother liquor resulting from the extraction of salt, as was the case formerly at certain plants before the recent demand caused by the European war sprang up, such mother liquor is directly evaporated for its saline content.

After the salt has been separated in the main grainers and the latter are ready to be cleaned, the bittern is further concentrated in another grainer or set of grainers to a specific gravity of 30° or 31° B. Of course, salt separates in this second set of grainers, after which the bittern goes to the calcium chloride works. Here the bittern is further concentrated to a strength of 45° B. The volume of this concentrated bittern is about 8.5 per cent of that of the original brine. The composition of this strongly concentrated liquor while at the boiling point is as follows:

Composition of calcium chloride liquor.

Calcium chloride (CaCl_2).....	34.50
Magnesium chloride (MgCl_2).....	11.60
Sodium chloride (NaCl).....	None
Water.....	53.90
	100.00

At Mount Pleasant the liquor from which the bromine has been recovered goes to the storage tanks of the salt block, where it is heated and agitated with milk of lime. After this operation ceases the suspended matter quickly settles, leaving a clear supernatant liquid above, which is evaporated in a modified form of open pan. After partial separation of the salt, the bittern is concentrated in another pan to 42° to 44° B. and is then run into a settling tank, where the rest of the salt settles out. The bittern is then boiled in a cauldron until all the water has been evaporated except that necessary for crystallization of calcium chloride. The liquid is then run into metal drums of 700 pounds capacity, where it solidifies, and in this form it is placed on the market. The liquid may be run in a viscous condition onto floors over which cold water is circulated in pipes. The sudden solidification produces a tension in the calcium chloride, and it may be readily broken by sledge hammers. It is passed through a rotary crusher, sized, and barreled for the trade.

Analyses of the product at different plants are as follows:

Analyses of calcium chloride obtained from natural brines in Michigan, Ohio, West Virginia, and Pennsylvania

RADICALS IN PERCENTAGE OF TOTAL WEIGHT

Constituent	1	2	3	4	5	6	7
K.	0 7	0 8	Trace	Trace	0 3	0 2	Trace.
Na.	6	2 4	3 7	Trace	0	1	None.
Ca.	19 5	19 6	18 5	24 6	18 9	15 4	30 4
Mg.	4 9	5 1	5 3	6 3	4 6	3 4	1 8
Cl.	50 4	53 9	53 9	62 0	43 9	42 6	59 0
SO ₄	None	None	None	1 6	None	None	Trace.
CO ₃	None	None	Trace	None	6	3	None.
Br.	76 1	81 8	81 4	94 5	69 8	64 7	91 4

CONVENTIONAL COMBINATIONS IN PERCENTAGE OF TOTAL WEIGHT

KCl	1 4	1 5	Trace	Trace	6	4	Trace.
NaCl.	1 6	6 1	9 4	Trace	0	3	None.
CaCl ₂	33 9	54 2	51 2	68 3	51 4	50 6	84 2
MgCl ₂	19 2	20 0	20 8	24 4	17 2	13 3	7 0
CaSO ₄	None.	None	None	2 2	2 9	2 5	Trace.
MgBr ₂	None	None	Trace	None	1 3	None	None.
Water by difference.	23 9	18 2	18 6	5 1	29 6	34 9	8 8
	100 0	100 0	100.0	100 0	100 0	100 0	100 0



- 1 Eureka Calcium Works, Pomeroy, Ohio, 1911 R. F. Gardiner, analyst.
- 2 Liverpool Salt & Coal Co., Hartford, W. Va., 1911 R. F. Gardiner, analyst
- 3 Hartford City Salt Co., Hartford, W. Va., 1911. R. F. Gardiner, analyst
- 4 J. Q. Dickinson & Co., Malden, W. Va., 1911 J. A. Cullen, analyst
- 5 Saginaw Chemical Works, Saginaw, Mich. Traces of barium and strontium, 1911 R. F. Gardiner, analyst
- 6 Van Schaack Calcium Works, Mount Pleasant, Mich., 1911 R. F. Gardiner, analyst
- 7 Pittsburgh Calcium Chloride Works, Pittsburgh, Pa., 1911 R. F. Gardiner, analyst

In this connection, the magnesium chloride content is of interest and importance.

The bromine content of the sample collected at the Saginaw Chemical Works, Saginaw, Mich., points to the nonremoval of the bromine after the crystallization of the salt and before evaporation to produce the final product. It should be noted that the samples whose analyses are given above were collected in 1911.

VACUUM-PAN PROCESS.

HISTORY.

On July 16, 1839, John Reynolds in English Patent No. 8155, outlined a process for improving the manufacture of salt by "causing the steam produced by boiling brine or salt water in a closed vessel to transfer its heat to and thereby boil brine or salt water in a second closed vessel, so that the steam from such second closed vessel may in like manner transfer its heat to brine in a third vessel, and so on, by maintaining in each of a series of closed vessels in which brine is subjected to evaporation such relative pressure as will cause the

respective boiling points of the brine contained in each to be lower from the first to the last of the series, so that the steam or vapor produced from the brine in each vessel may be condensed in a vessel of thin metal immersed in the brine of the next succeeding vessel. The graduations of pressure may be obtained either by diminishing a pressure superadded to that of the atmosphere, or by diminishing the pressure of the atmosphere alone.”^a

The principle of multiple effect evaporation, however, does not appear to have begun with the evaporation of brine for salt. A catalogue issued by the Zaremba Co., of Buffalo, N. Y., states that-

Vacuum pans were first used in 1813 in the form of single effects in the manufacture of sugar. These single effects comprised a single evaporator body consisting of a closed vaporizing element connected with a condenser and air pump, the heating element consisting of coils of piping submerged in the liquor. The liquor was subjected to but one ebullition in a given evaporator, hence the name “single effect.” Here the theoretical efficiency was 1 pound of water evaporated per pound of steam used.

The second great step in evaporator development took place in 1830, when Killeaux broached the idea of multiple effect evaporation, in which, as a result of performing several ebullitions under varying degrees of vacuum, the amount of work done by the steam is greatly augmented. He experienced great difficulty in introducing his improvement, so much so that it took 30 years to bring it into general use in European sugar factories.

So far as known, the first vacuum pan used in the United States for the manufacture of salt was started by Joseph M. and John H. Duncan, brothers, in the spring of 1885 at Warsaw, N. Y.

In the fall of 1880 the Duncan brothers were sent by the American Dairy Salt Co., of Syracuse, N. Y., to investigate salt-making machinery used in the East. The Duncans were particularly interested in the centrifugals and driers used in sugar manufacture, especially with reference to their possible adaptability for drying salt that came from the washing machines then in use. At that time all dairy salt was washed in machines with a solution of brine and soda ash to remove impurities.

The Duncans became greatly interested in the vacuum pans used in making sugar; but on being informed that it was impossible to crystallize the sugar in the pans, the subject was dismissed for the time being until it occurred to them that vacuum pans might be used in strengthening the weak brines of the Onondaga Indian Reservation. On further investigating the subject, it was concluded that the project was not practicable and the subject was dropped.

In 1883, Joseph M. Duncan left Syracuse to become manager of the Warsaw Salt Co., Warsaw, N. Y., where he erected and operated a large plant. After this plant had been placed in operation, experiments with vacuum pans in salt manufacture were again taken up,

^a Thorpe, Edward, Dictionary of applied chemistry, vol 5, 1913, pp. 12-13.

the strong brines at the Warsaw plant being used. An experimental pan, about 4 feet in diameter, was built along the same lines as are many of the vacuum pans in present-day use. Considerable trouble was experienced in crystallizing the salt, but after many experiments, success was achieved and the first salt made in a vacuum pan was produced. In the meantime, patents had been applied for.

Joseph M. Duncan later left Warsaw, and the brothers organized the Duncan Salt Co. and in 1885 took over the plant of the Silver Springs Salt Co. at Silver Springs, N. Y. During 1886 or 1887 they constructed a vacuum pan 7 feet in diameter. This was the first commercial vacuum pan constructed for the manufacture of salt. It was a success from the start, so far as the production of salt was concerned, but great difficulty was experienced with the salt and gypsum that so coated the tubes that they required boiling and boring out every few hours at great expense. This discouraging feature was gradually overcome as the Duncans became better acquainted with the brine and the proper treatment necessary to avoid these difficulties.

Their experience led them to design a pan with the tubes in sections, so that steam could be used on the inside of the tubes and the brine outside. This new type of pan gave better efficiency than the older pans and could be more readily cleaned. It also produced a much harder grained salt. However, the hard, small grain of the salt made difficult the marketing of the product. It received the name of "musical salt," for when put up in packages it gave forth a musical sound when the package was twisted, owing to the hardness of the crystals. Though small, the crystals were perfect cubes, and in hardness and shape were quite different from the crushed or ground salt then on the market.

The Duncan brothers were also the first to employ the centrifugal principle for drying salt. In their plant at Silver Springs the bottom of their vacuum pan was constructed with a series of valves, so that the salt could be drawn directly from the pan into the centrifugal without the aid of an elevator or other machinery. This method of production gave their product a reputation for cleanliness. The Worcester Salt Co., of Silver Springs, N. Y., formed by the union of the Duncan Salt Co. and the Nash-Whiton Co., employ pans of the sectional type.

The R. G. Peters Salt Co., of Manistee, Mich., so far as known, were the first to employ the vacuum pan in making salt in Michigan.

PRODUCTION CENTERS.

The vacuum-pan process is used in nearly all districts of the United States in which much salt is produced by evaporation. It is used in New York at Silver Springs, Ithaca, Ludlowville, and Watkins. In

Michigan salt is made by the vacuum-pan process at Del Ray, Wyandotte, and Ecorse, south of Detroit, and along St. Clair River at Port Huron, St. Clair, and Marine City, as well as at Ludington and Manistee and its suburbs in the western part of the Lower Peninsula. It is also used at Kenmore, Wadsworth, Cleveland, and Rittman, Ohio, Hutchison, Kans., and near San Mateo and Alvarado and in San Francisco, Cal.

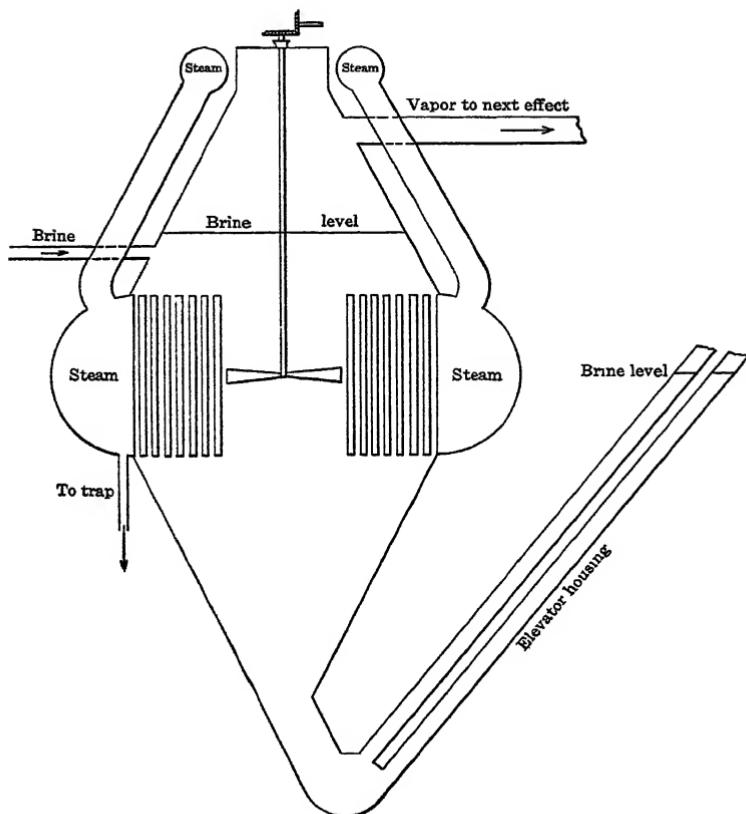


FIGURE 4.—Essential parts of vacuum pan

CHARACTER OF PRODUCT.

The salt produced by the vacuum-pan process has a fine luster and a closely even grain, which adapts it for table and dairy use. The crystals have nearly perfect cubical shapes that distinguish vacuum-pan salt from that made by other processes. The fine grain is due chiefly to the rapidity with which the salt crystallizes, and the rapidity of crystallization depends on the degree of vacuum, amount of steam, the height of brine in the pan, and other factors.

PRINCIPLE OF VACUUM-PAN PROCESS.

The vacuum-pan process in which multiple-effect evaporators are used represents the latest development in salt making. The apparatus used in it is more complicated than that employed in any other phase of the industry. The underlying principle of the process is the lowering of the boiling point of a liquid that results from decreasing the pressure of the vapor above the liquid. If a vessel of water is placed under the jar of an air pump and the air is partly exhausted the water will boil at a lower temperature than under ordinary atmospheric pressure, and the lowering of the boiling point will be greater the more nearly a perfect vacuum is approached. In vacuum-pan practice nearly complete exhaustion of the chamber can not, of course, be maintained, but the partial vacuum that is practicable effects appreciable lowering of the boiling point of the brine and consequently a distinct saving in fuel. For example, when the steam, which is the means of heating the brine, is at a temperature somewhat higher than 212° F. and the brine under partial vacuum boils at about 150°, water will rapidly evaporate from the brine.

Inasmuch as the boiling point of a liquid varies with the pressure to which it is subjected it follows that adjusting the pressure will produce corresponding changes of the boiling point, whereby it may be placed at will anywhere between certain practical limits. The lowest point is usually fixed by the cost of procuring the vacuum and is about 125° F. The upper limit is fixed by the temperature of the steam used, which for exhaust steam is about 225° F.

Obviously, with a given amount of heat for boiling, better results may be accomplished in a vacuum than under atmospheric pressure, and the greater the vacuum the greater the accomplishment with a given number of heat units. If, then, the cost of maintaining the vacuum, including the cost of the plant and its operation, is less than the value of the heat gained, evaporation of water by the vacuum-pan process is more economical than by the open-pan process.

With the open-pan process the heated vapor, containing a considerable quantity of heat units, is entirely lost, whereas in the vacuum-pan process in multiple effect this heated vapor is used to the greatest effect. A point that should be firmly borne in mind is that with the multiple-effect vacuum-pan system, each vacuum pan acts not only as an evaporator, but also as a boiler producing heated vapor or steam for boiling in the next succeeding pan and as the condenser for the pan immediately preceding. To make this point clearer, let assumptions be made as follows: The operation starts with steam from a main boiler plant that has a temperature slightly in excess of 212° F. The steam is led through pipe of suitable diameter into the steam belt of the first vacuum pan and is there condensed. The heat is transmitted through the tubes and absorbed by the liquor to be

boiled, which is under a vacuum of 15 inches. The liquor in boiling gives off heated vapor or steam, which passes as such to the steam belt of the second or No. 2 vacuum pan. This steam or vapor, instead of being at a temperature of 212° F., is at the temperature involved in the 15-inch vacuum—that is, approximately 175° F. With the liquor in the second effect under a vacuum of, say, 24 inches, the steam or vapor passing into it is amply hot to cause violent ebullition to take place. The ebullition in the second effect in turn produces heated vapor or steam, which is led to the steam belt of the third pan, which is under a vacuum of 27 inches. The steam from the second effect, which is at a temperature of 140° F., is amply hot to produce boiling in the third pan at the desired rate. The steam from the pan in which the vacuum is 27 inches at a temperature of 110° F. is again in turn hot enough to produce boiling in the fourth effect, which may be assumed to carry a vacuum of 28½ inches.

CONSTRUCTION OF APPARATUS.^a

The vacuum pans usually are vertical cylinders with conical ends and are commonly constructed of iron or steel, though a vacuum effect at one plant is built of copper heavily lined with tin. The detail drawings indicate their construction. The pans are installed singly, in pairs, in threes, and in fours, and with their mechanical attachments are referred to as "effects." Thus a single pan is a single effect, two pans in series a double effect, three pans a triple effect, and four pans a quadruple effect. Series of two or more pans in general are referred to as multiple effects. Pans less than 9 feet in diameter are not common and most are between 10 and 20 feet in diameter. With the constantly increasing demands for evaporators of large size, pans with diameters greater than 20 feet are becoming increasingly common, and a pan has recently been made with a diameter of 30 feet. (Pl. XV.)

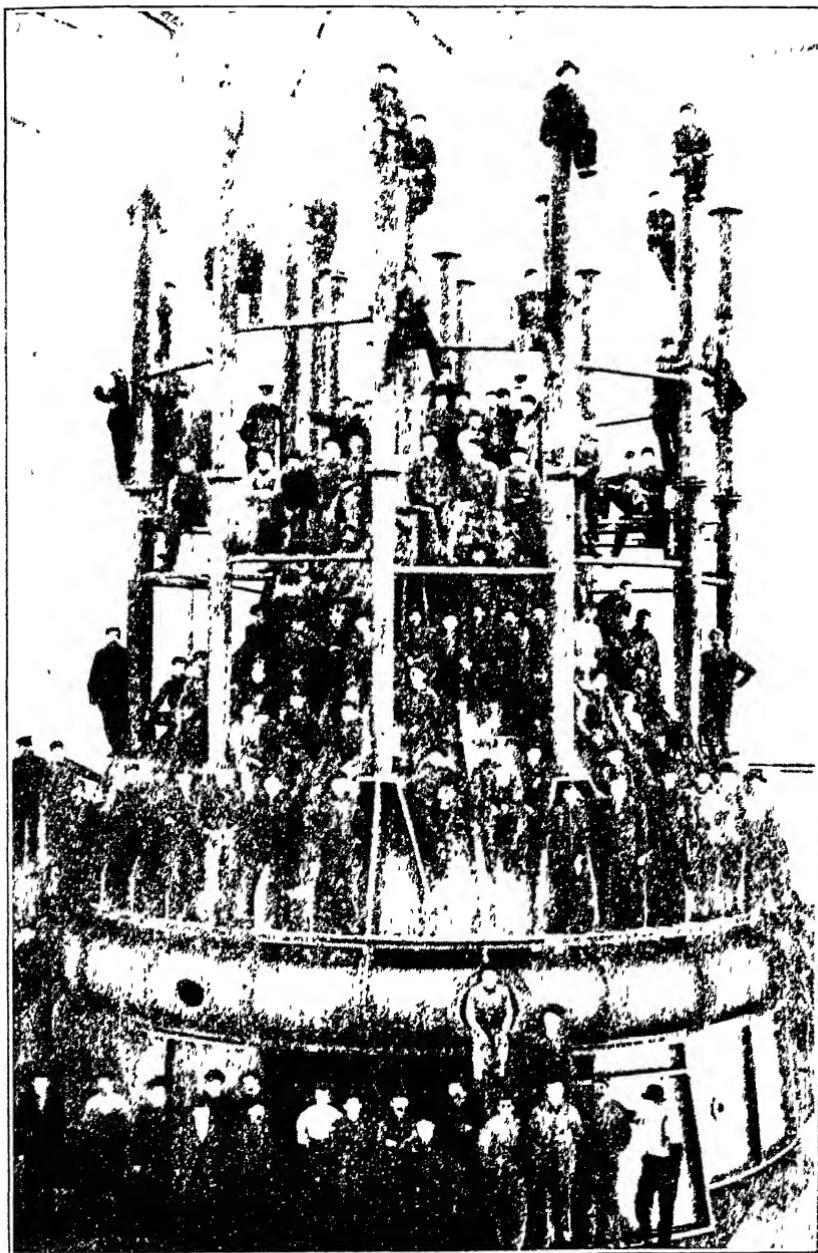
Pans 10 to 20 feet in diameter usually measure 30 to 50 feet from tip to tip of the end cones (see Pls. XVI and XVII and fig. 5), and therefore they have to be tended from different floors.

The steam belt is placed in the cylindrical part of the effect. It consists of a ring-shaped belt of several hundred vertical copper tubes about 5 feet long and 2 inches in diameter.

The warm brine from the preheating or settling tanks ^b enters the pan at different places in various makes of pan. At Silver Springs, N. Y., the brine enters near the 14-inch gate valve. (See fig. 5.) At Del Ray, Mich., the brine enters about 6 feet above the salt outlet, and the salt is thus washed with a solution of pure brine. At another

^a Specific points in construction are given in the descriptions of individual makes of pans in subsequent pages.

^b Cold brine goes to the vacuum pan at one plant in Ohio, but this is very unusual.



THIRTY-FOOT PAN (LARGEST IN THE WORLD AND CAPABLE OF PRODUCING IN TRIPLE EFFECT 1,000 TONS OF SALT A DAY) LOWER CONE, STEAM BELT, TAPER PLATES, AND COLUMNS, INVERTED ON ERECTING FLOOR WORKMEN PUT ON TO SHOW PROPORTIONS (COURTESY OF MANISTEE IRON WORKS, MANISTEE, MICH.)

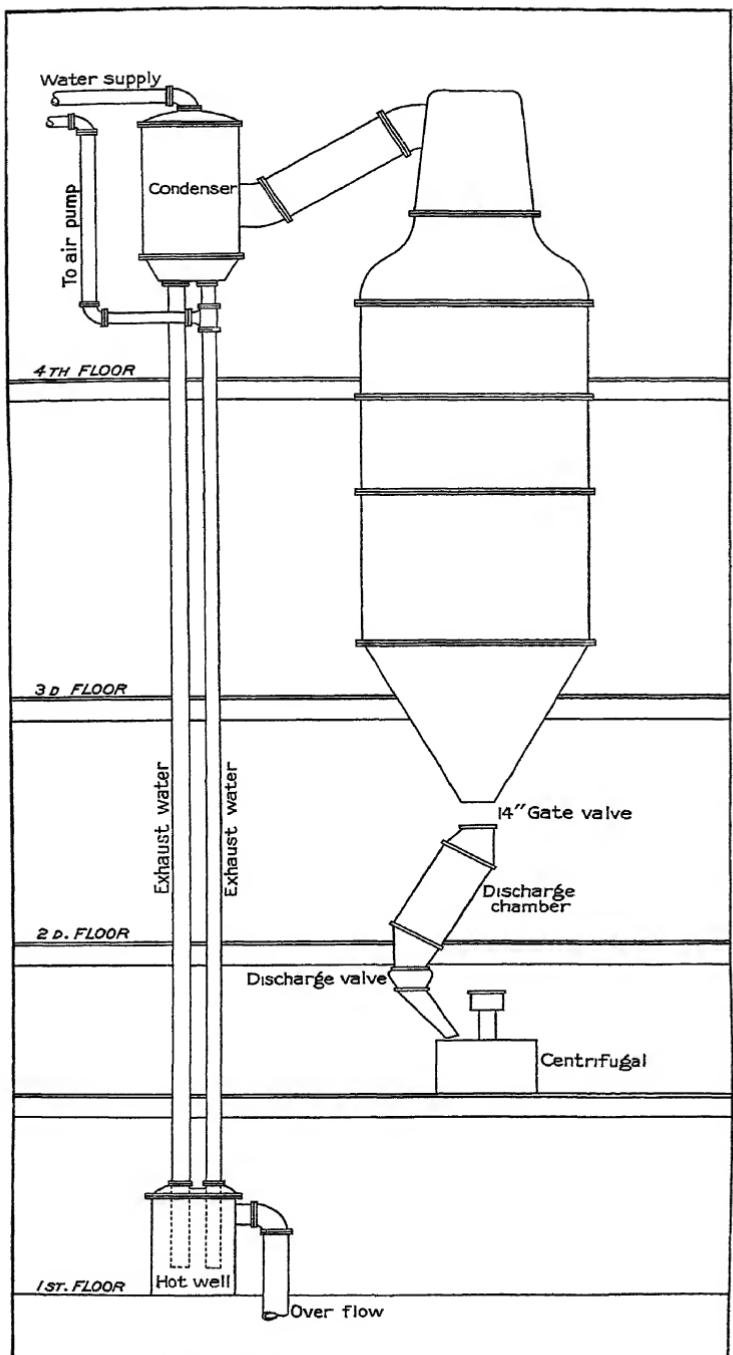


FIGURE 5.—Section of a single-effect vacuum pan, with gate valve, discharge chamber, and centrifugal salt box. This type differs from those shown in Plates XVI and XVII in the method by which the salt is removed.

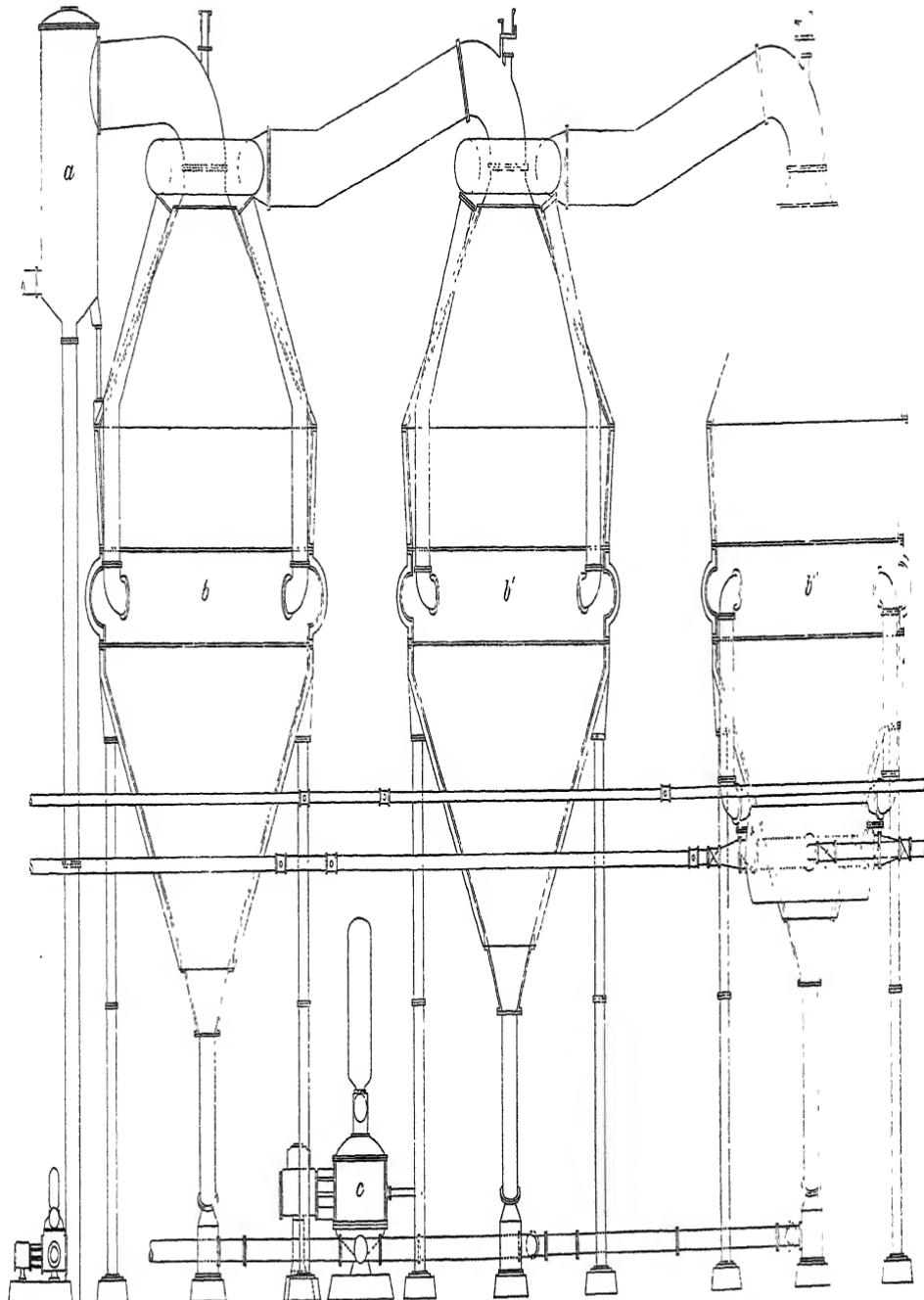
plant the brine enters near the base of the pan during the preliminary filling but above the steam belt after the operation is well under way. Introduction of the brine above the steam belt is the usual method. The brine is boiled at a low temperature, depending on the vacuum maintained, and as the salt forms it falls by gravity into the elevator boot and is carried by an endless-chain elevator to the draining bins, from which it is taken to the storage bins after it has drained a sufficient length of time.

DETAILS OF OPERATION.

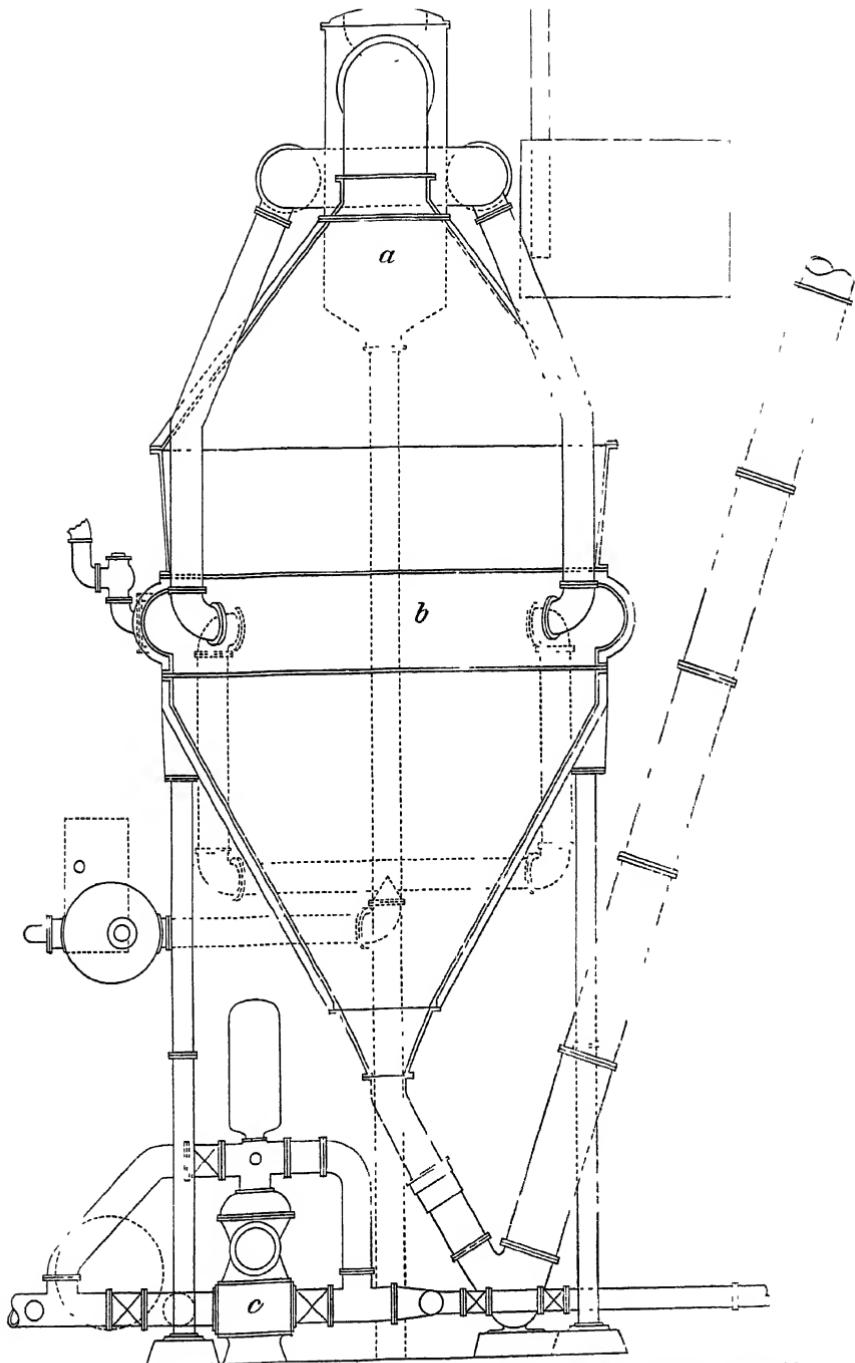
MANISTEE EVAPORATOR.

The details of operation differ with the make of pan and with the individual in charge. For general descriptive purposes the manipulation of the Manistee pan has been selected, as it is a type in common use. Other makes are described subsequently. The steam, either direct or exhaust, enters the steam belt usually but not always at rather low pressure. It is led to a ring surrounding the top of the effect, and thence through pipes to the steam belt below. The condensed water, which is trapped off from the steam belt of each effect, may be used in the manufacture of artificial ice, in boiling out the pans, or in the boilers of the plant, or it may be thrown away. It may be brackish in all but the first effect. As the brine boils, the steam rising from it in the body of the first effect passes through a gooseneck into the steam belt of the second effect, the steam from the body of the second effect passes likewise through a gooseneck into the steam belt of the third effect, and so on throughout the series. The body of the last effect is connected with a vacuum pump, and the vapor is condensed by a jet condenser, thus helping to maintain the vacuum. Theoretically, the vacuum produced by the pump at the beginning of the operation ought to be kept up by the condensation caused by the flowage; the working efficiency is, however, not perfect, and the vacuum pump is operated all the time. The condensing water is usually allowed to go to waste, but at some plants a use is found for it, such as dissolving the salt underground. Its temperature is low, 80° to 90° F., so that not much heat is lost, and it is usually brackish.

The vacuum in the body of a single effect, measured in inches of mercury, ranges from 25 to 28 inches. At one plant where triple effects are used the vacuums in the first, second, and third effects were 15, 24, and 27 inches, and at another 14, 18 to 20, and 28 inches. The water in the effects boiling at correspondingly low temperatures. The aim is to maintain in the last effect a vacuum as nearly perfect as practicable. As the degree of exhaustion decreases progressively from the last to the first effect the brine boils at the highest temperature in the first effect and at increasingly lower temperatures in the others.



SIDE ELEVATION OF A TRIPLE-EFFECT VACUUM PAN. (COURTESY OF MANISTEE IRON WORKS CO., MANISTEE, MICH.)



END ELEVATION OF TRIPLE-EFFECT VACUUM PAN (COURTESY OF MANISTEE IRON WORKS CO.,
MANISTEE, MICH)

As the solution boils it is in constant circulation, which may be assisted by a revolving wheel, which creates a downward current and consequently a return upward current through the copper flues in the steam belt. Thus salt crystals formed in the brine as it passes through the flues are carried by the propeller and gravity downward toward the boot.

As there is a constant tendency for the copper flues to become clogged with salt the pans are boiled out frequently in order to keep the heating surface of the flues perfectly clean and at their maximum efficiency. The brine drawn from the pan before boiling out goes either back to the settlers or to another pan. As bittern is formed rapidly in the vacuum-pan process the brine becomes impure after a few admixtures with such residual liquors and has to be entirely discarded at intervals.

The boiling out is usually done with fresh water once or twice a day to twice a week, the frequency depending in general on the rate of operation. At less frequent intervals, depending on the amount of gypsum in the brine and the rate of operation, the pans are cooled and the gypsum scale is removed from the copper tubes in the steam belt, usually by boiler-tube cleaners operated by compressed air. Scaling and boiling out are essential to keeping the pans at their maximum efficiency. Calcium sulphate, gypsum, or plaster, as it is variously called, is one of the main difficulties with which the salt manufacturer has to contend, and it is carried in greater or less amount by the brines of nearly all the important salt fields. It causes interruption to the process and laborious cleaning out, and it not only entails great loss of heat because of its low conductivity but it also causes the overheating of any metal exposed to direct fire. After a pan has been boiled out it sometimes makes salt that is not completely soluble in water or is otherwise unsatisfactory. Therefore, the first few dumps of salt made after a pan has been boiled out are usually not first class. If a pan makes off-color salt or salt that gives a cloudy brine it may be necessary to boil out more frequently or perhaps to change brine.

The salt as it forms settles into the lower part of the effect and into the elevator boot. As the brine in an effect is under a partial vacuum the level of the brine in the elevator housing above the boot is lower than that in the pan. (See fig. 4.) The salt passes through the brine in the elevator housing in the endless bucket conveyor, which is usually inclined (see fig. 4), though at one Ohio plant it is vertical, claim being made that this arrangement saves wear and tear. The salt is conveyed in the elevator either to bins with false bottoms, in which it is allowed to drain, or to a centrifuge, by which the excess of moisture is removed. The dry salt is then conveyed to the storage bins. The drippings are usually returned to the pan.

Another modification of the vacuum pan, used at a few plants in the United States, is distinguished by the method of discharging salt from the bottom of the pan. (See fig. 5). The peculiar feature of this pan is the discharge valve, through which the operator can draw off the bittern with each dump of salt. When the pan is being operated, the discharge valve is closed and the gate valve is open. After the discharge chamber has been filled with salt the gate valve is closed and the discharge valve below is opened. In this manner the salt and the bittern are removed without loss of vacuum in the pan, the discharge chamber playing a rôle similar to that of an air lock in the pneumatic method of excavation. By this arrangement the salt may be dumped 4 or 5 times an hour or about 100 times a day. The mixture from the discharge chamber runs into a centrifuge, by which the moisture is reduced to the practical minimum, the mother liquor running to the sewer. The salt is then ready for the next stage in the process of preparation for market.

OTHER TYPES OF EVAPORATORS.

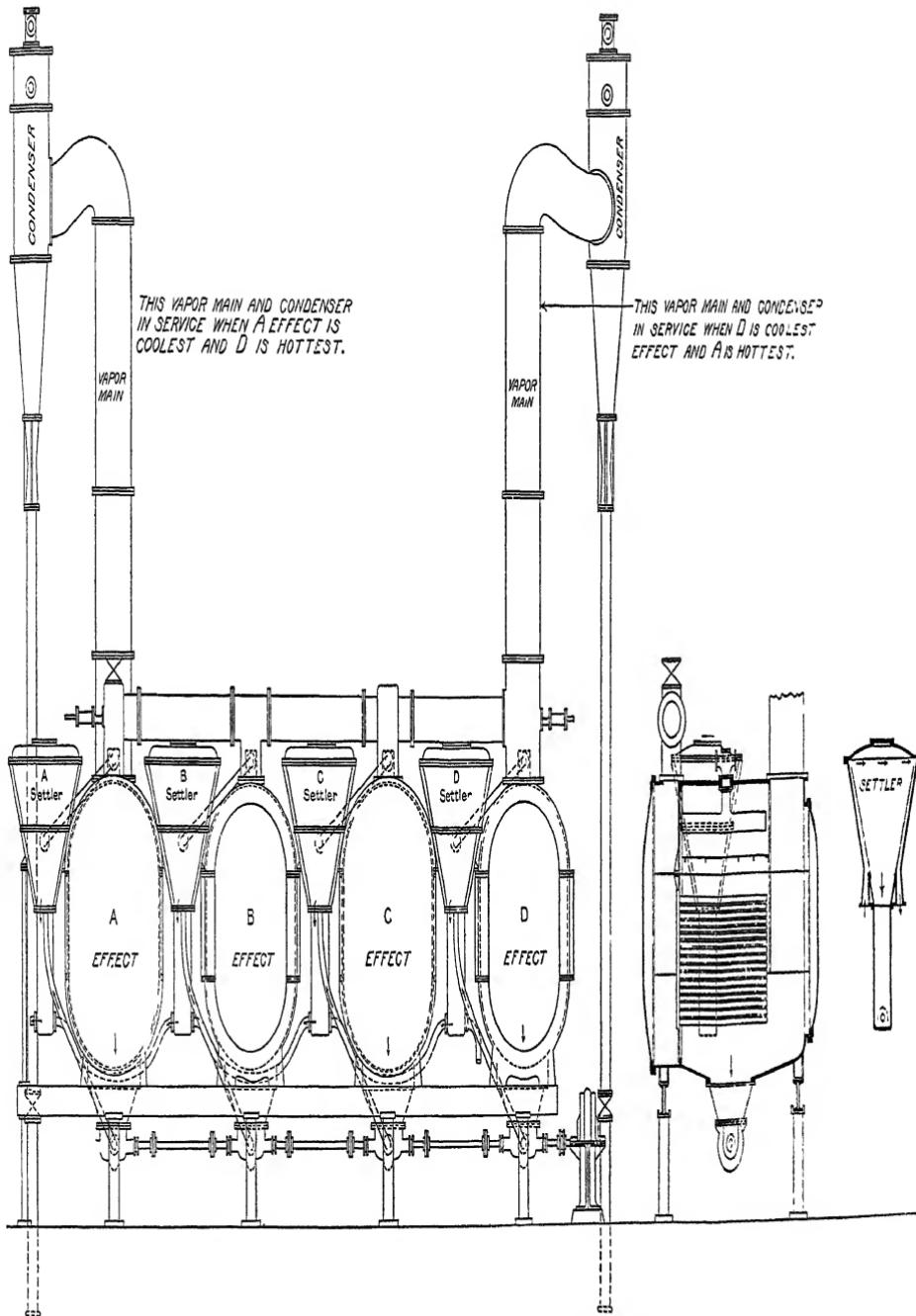
In 1916, the author visited many plants making single and multiple effect salt evaporators. If a personal visit was not practicable, information was requested by letter as to special types of evaporators. Brief descriptions of the different types follow. Some descriptions have been obtained from catalogs issued for public circulation, and others have been abstracted from a report by Cole.^a It is requested that manufacturers communicate with the writer if they make a salt evaporator of a type different from any described in this report. Information from manufacturers regarding corrections to the descriptions of their special makes will be gratefully received for future editions of this report, if such are issued.

LILLIE EVAPORATOR.

Certain manufacturers of salt use a type of Lillie quadruple-effect evaporator that differs in several respects from the above described type and which has been developed from the evaporator used in the evaporation of sirup from cane juices. (See Pl. XVIII.) Some of its distinctive points are film evaporation and mechanical circulation, the manner of distributing the circulating liquors over the horizontal unsubmerged evaporating tubes, and the reversal at will of the course of the vapors or the heat through the multiple effect.

The effects have the form of cast-iron horizontal drums set side by side with the steam end of one adjacent to the vapor end of the next, the copper tubes that provide the heating surfaces being set

^a Cole, L. H., The salt deposits of Canada and the salt industry: Canada Department of Mines, Mines Branch, 1915, pp. 124-125.



SECTION THROUGH QUADRUPLE-EFFECT LILLIE EVAPORATOR.

near one end of each effect.^a The steam is trapped from the steam end of the first effect to the steam end of the second and mixes there with the steam, evaporated from the brine of the first effect. The steam in the third effect is supplied by steam trapped from the steam end of the second and the vapor from the second, and so on. The vapor end of the last effect is connected with a condenser and this in turn with a vacuum pump used to start the apparatus and to remove occluded air or gas from the brine. The brine and salt are moved by a centrifugal pump set in the middle of the apparatus on a horizontal shaft that extends throughout the entire length of the apparatus and carries connected with the hopper of each effect smaller centrifugal pumps that agitate the brine in its effect but do not move it forward. The salt carried with the brine exerts on the apparatus a scouring action which keeps it free from scale.

Another aid in keeping the apparatus clean is the periodical reversal of the flow of steam and brine, by which the first effect, which is under one set of conditions the hottest, becomes the coolest and the last effect becomes the hottest. The salt and brine ordinarily go from the first effect to the adjacent settler, from which the brine and some of the salt go to the second effect, but they may go immediately to the second effect and so on to the end of the apparatus. Thus the salt produced in all effects may circulate in the last effect and cause considerable scouring. Each effect draws sufficient brine from the brine line to keep the brine in the effect at the proper level.

Some descriptive details abstracted from a prospectus issued by the company making the apparatus follow:

The evaporating tubes incline slightly downward toward the steam end and open through the heavy tube-plate partition, in which they are firmly expanded without annealing and by which they are supported. The other ends of the tubes are closed, save for a small air vent in each, and are not fastened or supported, thus being free to expand or contract independently of the shell of the effect. The centrifugal circulating pump underneath and midway between the ends of the evaporator is sometimes omitted, in which case the liquor rises in the body sufficiently to float the feed-valve ball float that regulates the feed into the body. In a multiple effect the steam condensed inside the tubes flows into the steam end and thence through a steam trap into the steam end of the next cooler effect and finally into the atmosphere from the coolest effect. The solution circulates over the tubes in a deluging shower maintained by the centrifugal pump. The circulation is independent of ebullition.

The perforated distributing plate above the tubes is formed in sections for convenience in handling. Above each vertical row of

^a Young, C. M., Notes on the evaporated salt industry of Kansas Eng. and Min. Jour., vol. 83, Sept. 18, 1909, pp. 558-561.

tubes it has one row of holes, three-eighths inch and greater in diameter. The heavy flow of solution down the surface of the tube plate through the inch space between the distributing plate and the tube plate prevents matter from caking on the tube plate, and the flow of solution through the inch spaces on either side of the tube plate prevents clogging of the perforated plate by particles of scale and other solids. This foreign matter is discharged from each effect with the liquor and is finally discharged from the last effect.

The circulation of both vapors and brine or of either alone may be reversed. Reversal of either permits taking the dilute solution into the coolest effect and delivering it concentrated from the hottest effect when desirable; that is, when a liquid is to be concentrated to a high density.

BRECHT SALTING EVAPORATOR.^a

The Brecht salting evaporator is manufactured by the Brecht Co., St. Louis, Mo. It can be operated in either single or multiple effect as required.

It consists, essentially, of three parts—the evaporator shell, the heating chamber, and the salt filter. (See Pl. XIX.)

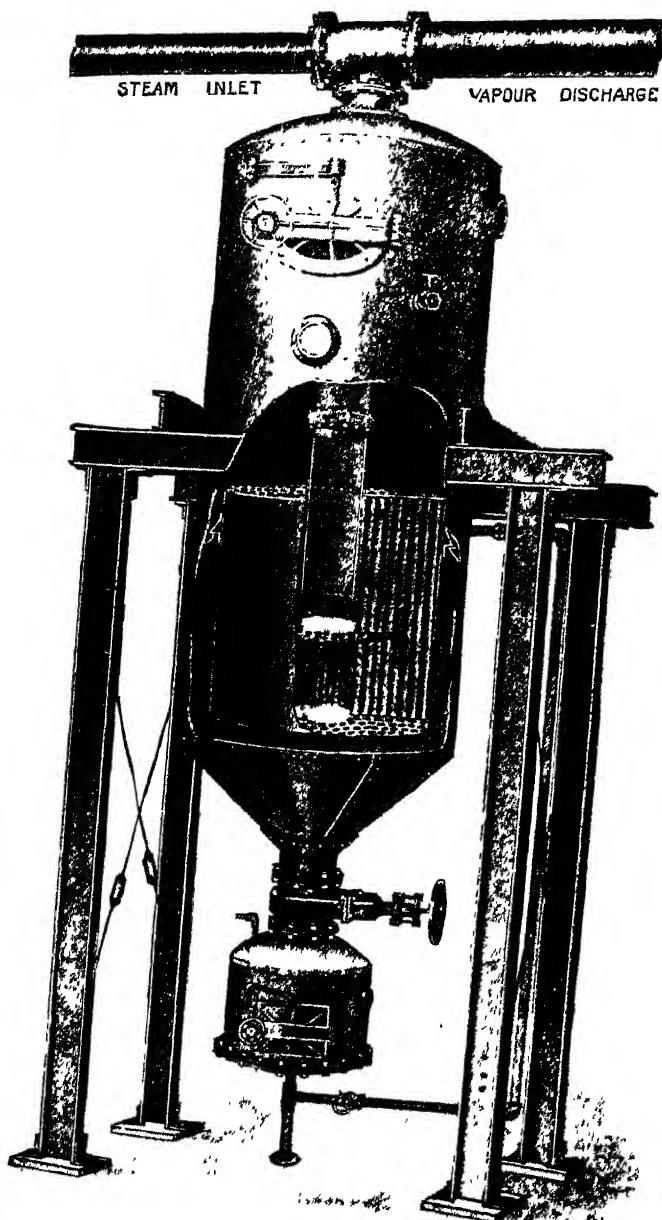
EVAPORATOR SHELL.

The evaporator shell is generally made of steel and is cylindrical, with domed top and cone-shaped bottom. Suitable observation holes and a water gage are attached to the cylindrical body, and an air-tight manhole is placed near the top.

HEATING CHAMBER.

The heating chamber is one of the essential features of the Brecht evaporator. It consists of a steam drum in which a number of steel or copper tubes are placed vertically. These tubes allow the brine in the evaporating chamber to circulate freely to the cone-shaped bottom and to return again to the upper part of the evaporator. The drum is cylindrical and fits within the steel shell, where it is suspended on lugs attached to the side. The steam, from which the heat is obtained, enters the top of the drum, and, by a series of baffle plates so arranged that the direction of the steam travel is at right angle to the tubes, all the tubes are heated equally. The steam is thus constantly in circulation until it condenses and is drawn off by suitable means from the bottom of the drum. The tubes are made of either steel or copper, as required, and are 4 inches in diameter, the large bore obviating clogging as the salt crystals form.

^a Cole, L. H., The salt deposits of Canada and the salt industry: Canada Department of Mines, Mines Branch, 1915, pp. 124-125.



BRECHT EVAPORATOR

entrainment. The steam chest is fitted at the top and bottom with tube plates, into which are expanded a number of $2\frac{1}{4}$ -inch copper tubes. The downtake is in the center of the steam chest, and is of sufficient size to prevent the clogging of the salt crystals as they are formed. The brine circulates up through the copper tubes and down the central downtake. The salt crystals, as formed, drop into the

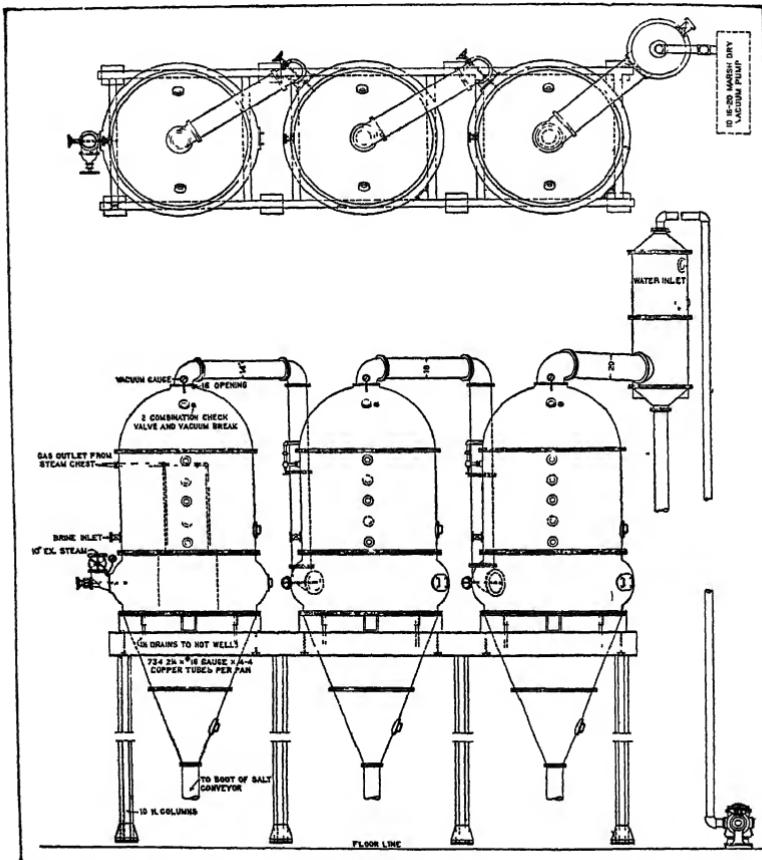
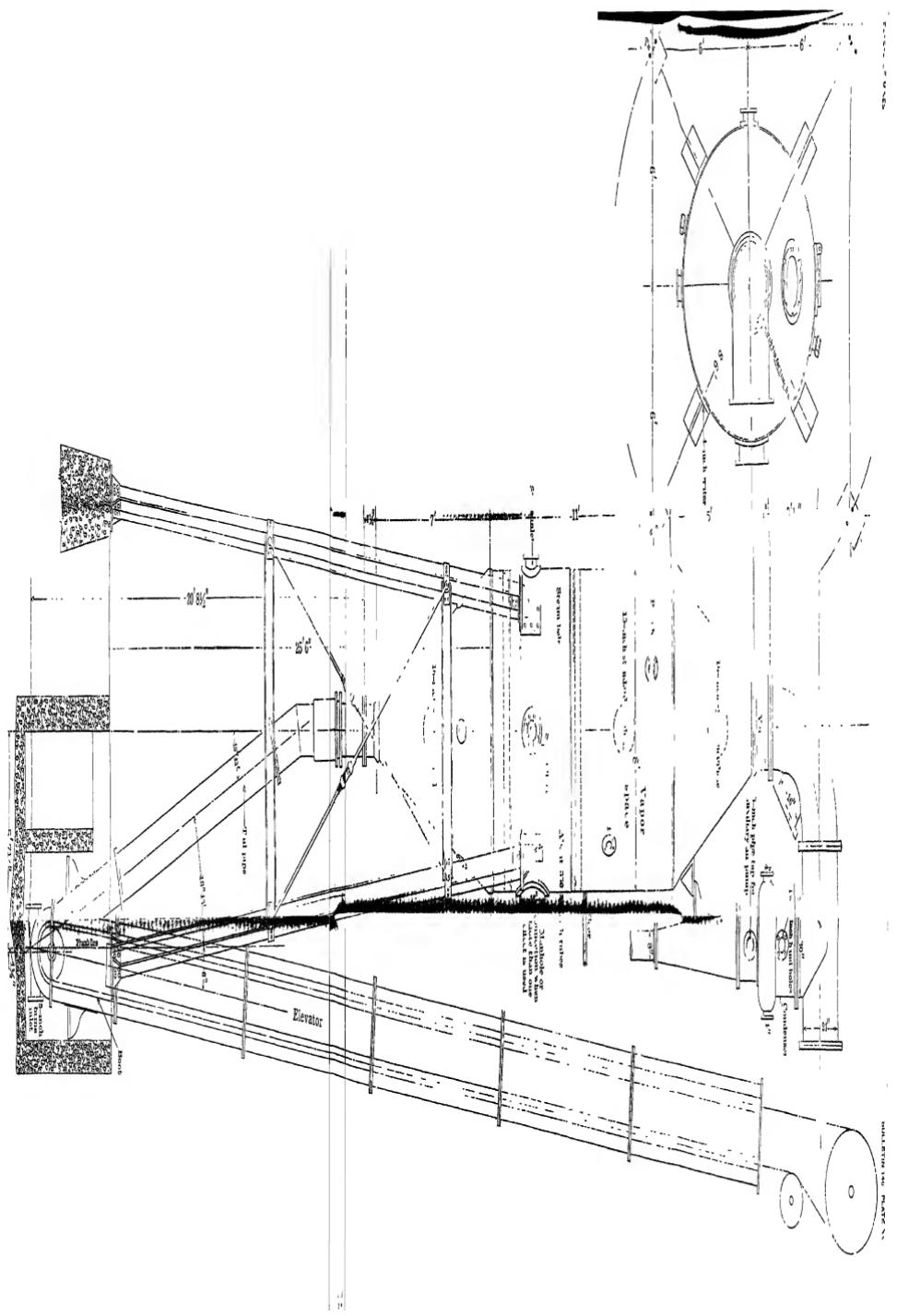


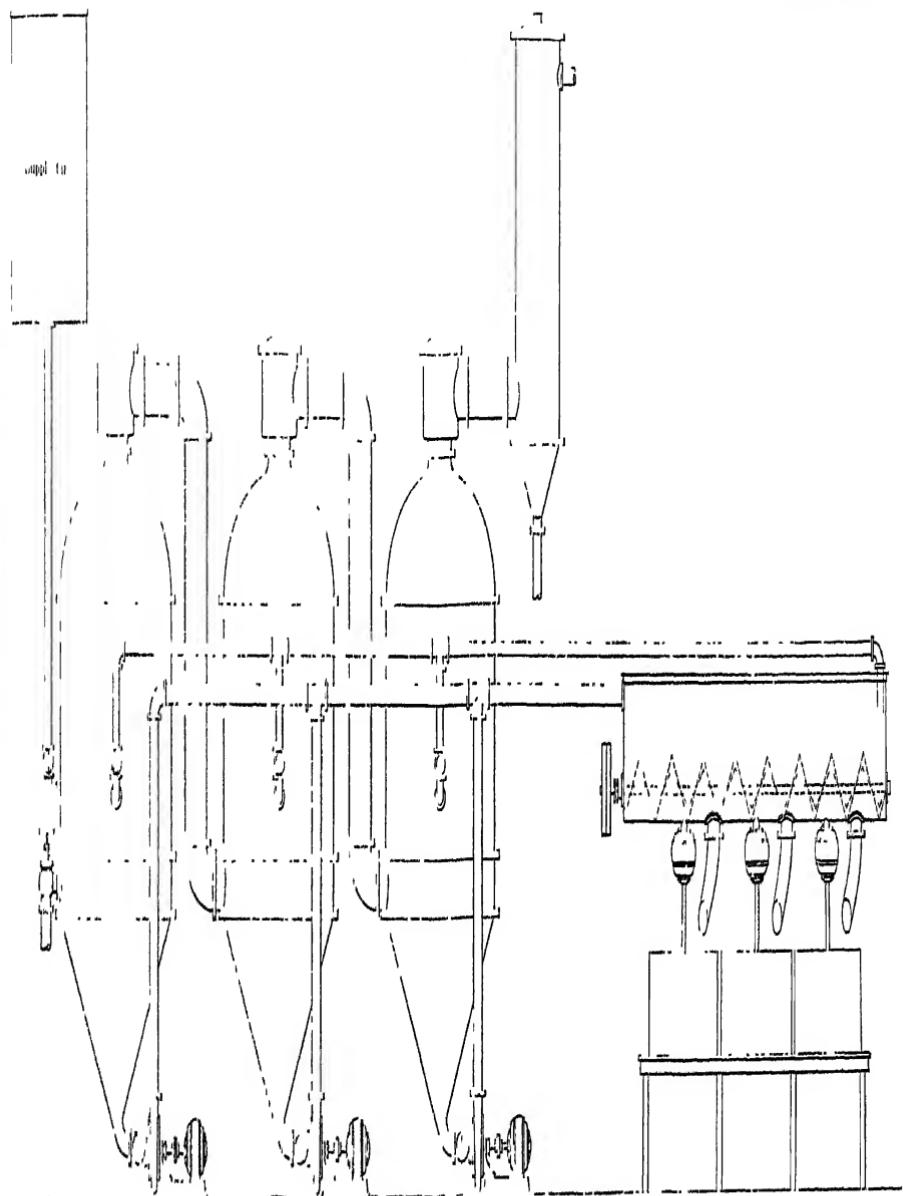
FIGURE 6.—Swenson triple-effect evaporator.

quieter part of the cone-shaped bottom, through the barometric leg into the boot of an inclosed elevator, which drops them into the drying bin.

OPERATION.

The operation of an evaporator of this type is continuous. Suitable means are provided for the removal of the inclosed gas in the steam chest as well as the condensed steam. The evaporators can be operated either in single or multiple effect.





OSCAR KHENZ EVAPORATOR

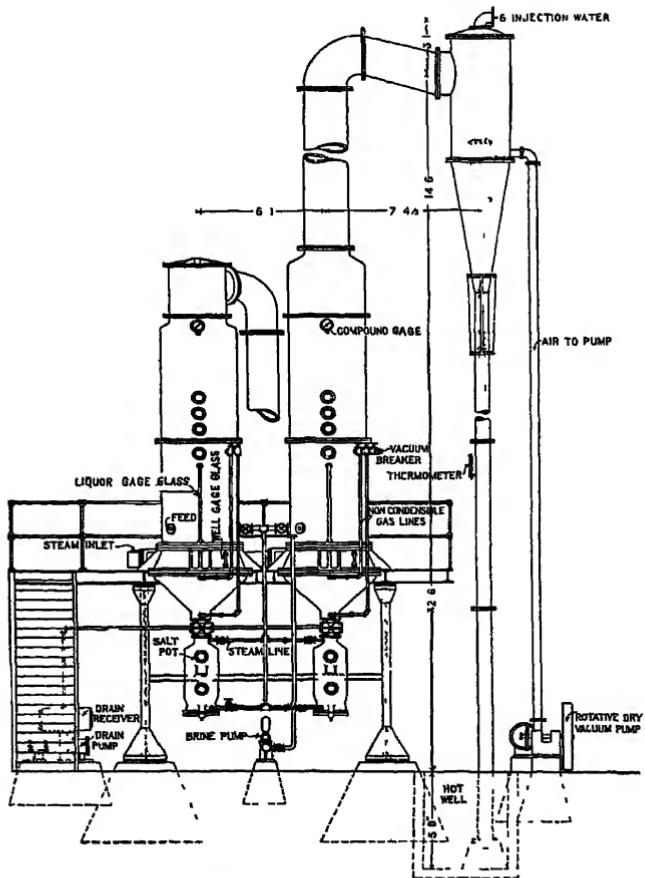
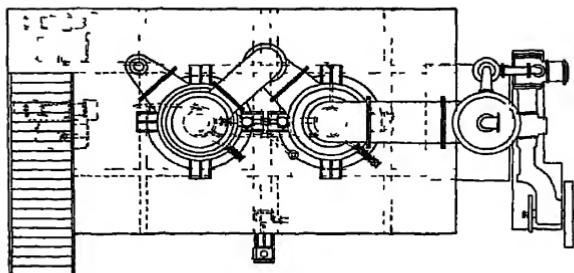


FIGURE 7.—Sanborn salt evaporator

WHEELER EVAPORATORS

Wheeler evaporators (fig. 8) and multiple effects with standard, vertical-tube calandrias are best known in the sugar industry, where many are in service.

The pan of each vessel is usually of cast iron with a dish-shaped bottom, above which is the steam-belt course, and above this, the courses forming the vapor space and dome. Above the dome is a catch-all, which returns the unevaporated liquid entrained in the vapor to the boiling space. The steam belt contains the calandria, which consists of vertical tubes 2 to 3 inches in diameter, secured into horizontal circular tube plates. Steam circulates on the outside of the tubes, and the liquid to be concentrated boils within the tubes. The circulation of the liquid is upward through the tubes and downward through the down-takes.

In the evaporation of salt solutions particular attention is given to the removal of crystals. These are thrown down from concentrated solutions and must be removed continuously. Removal is accomplished by duplicate filter boxes, or by a long settling leg provided with a strainer and a continuous carrier.

The vertical tubes of a calandria are cleaned periodically, the intervals between cleanings depending on the service. Often, as in sugar houses, the tubes are treated with diluted solutions of acids, which soften and loosen the scale. A wire brush, rotated by an external-air motor, is then run through the tubes, or a turbine cleaner is used, similar to that used for cleaning water-tube boilers. For steel calandria tubes a cutter head is used, and for copper tubes a thin wire brush head.

Vacuum or strike pans are built with horizontal copper coils, as well as with tubes as described.

ZAREMBA CRYSTALLIZING EVAPORATOR ^a

CONSTRUCTION

The Zaremba crystallizing evaporator consists of two parts: (1) The evaporator body, in which the evaporation occurs, and (2) the salt filter underneath, by means of which the precipitated crystals are separated from the concentrated liquor, washed clean, and removed from the system.

HEATING SURFACE

The shell of the evaporator body is built of heavy cast iron or steel. Its lower part, below the heating surface, consists of a cone into which the salt is precipitated and funneled into the salt filter below.

^a Data furnished through the courtesy of Edward Zaremba of the Zaremba Co.

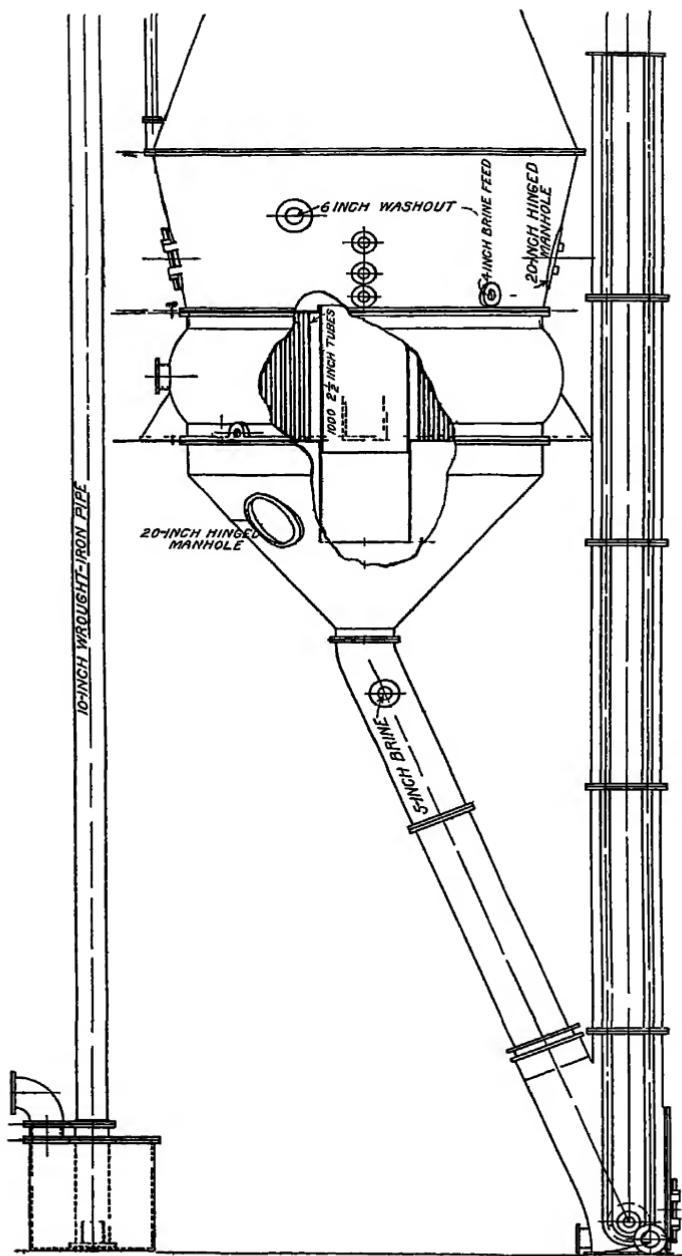


FIGURE 9.—Wheeler salt evaporating pan with continuous elevator

Mounted within the shell immediately above the cone is the cylindrical steam chest, fitted at top and bottom with disked heads of steel into which 2-inch charcoal-iron tubes are expanded. The fastening of the steam chest in the shell is effected by means of a special design. The tubes are slightly inclined from the vertical to facilitate circulation and prevent possible loss of liquor. Copper tubes may be used for corrosive liquids.

CIRCULATION

The downtake is an annular opening, widest at the bottom, extending entirely around the steam chest. Circulation of liquor is upward through the tubes, outward toward the top of the downtake, downward between the steam chest and the exterior shell, and then inward to the lower end of the tubes. This action produces a ready separation of the salt crystals from the boiling liquor, throwing them into a zone of quiet in the conical bottom and thence into the salt filter.

SALT FILTER

The filter consists of a cylindrical chamber fitted with a filter screen placed close to the bottom. At the front and immediately above the screen is a swinging door through which the separated salt is removed. The conditions inside can be observed through the sight glass. Wash water is introduced through perforated pipes mounted under the top cover of the filter. Vacuum and liquor pumps connected to the system are adequate to provide for all requirements.

METHOD OF OPERATION

Evaporator — The brine or weak liquor enters the first effect at the top of the cone and flows to the base of the steam chest. By the action of the vapor generated in the tubes and the pressure exerted by the liquor in the downtake, a vigorous movement is set up within the tubes (about 30 feet per second), inducing rapid heat transmission and effective scouring action on the tube interiors. Owing to the large area of the downtake the return flow to the bottom of the steam chest is slow (about 3 feet per second or less), allowing the crystals formed during the concentration to separate from the liquor and drop gently into the zone of unagitated liquor contained in the cone. The heavy liquor carrying these suspended crystals flows out through the plug cock at the tip of the cone and into the salt filter.

Filter — A liquor line connects the bottom outlet of the filter to the liquor inlet of the second effect, which, being under a higher vacuum, draws the liquor through the filter and into itself by suction. The suspended crystals are left behind on the filter screen, where they are allowed to accumulate until the salt filter is filled, as indicated by a sight glass. The connection between the evaporator

and the filter is now shut off by closing the plug cock between, and after the heavy liquor has been drawn off the contents of the filter are washed with weak liquor, hot water, and steam. The connection to the second effect is then closed, the discharge door of the filter is opened, and the thoroughly washed crystals are removed in an approximately dry condition.

After the filter has been emptied its door is closed and the contained air is removed by replacing it with steam. The condensation of the steam soon produces sufficient vacuum to pull the mixture of liquor and salt collected in the cone down into the filter, when the plug cock is opened. The liquor level in the evaporator is again brought to standard height and the filter is placed in circuit by opening the connection to the next effect. Where the quantity of salt precipitated is comparatively large two filters are attached to one evaporator body, thus making it possible always to have one filter connected to the evaporator, inasmuch as the filters are used alternately. By either arrangement the salts are washed and removed without interfering with the work of the evaporator above. If desired, the crystals can be dissolved within the filters and the saturated solution removed by pumping.

The method of operation in the second effect is the same as has been described, except that the heavy liquor is drawn from the filter by the suction of a pump. The liquor discharged from this pump is returned to the second effect to be recirculated.

These evaporators are built either as single, double, triple, or quadruple effects, and are generally connected in such a manner that any one of the bodies can be cut out of service without interfering with the others. Owing to the fact that each body of a multiple effect operates at a different temperature, by proper manipulation it is frequently possible to make a separation of salts where several compounds are present in the solution. Ordinarily, the weak liquor is fed to the hottest body and is finished in the coolest body, but for some purposes the flow of the liquor is reversed, thus giving what is known as the "countercurrent" system of working.

By installing a preheater for feed liquor a substantial reduction in the amount of steam used is possible. The evaporators are equipped with internal separators, which makes impossible the carrying over of liquor by entrainment as a result of careless operation.

The steam pressure used varies all the way from atmospheric to 60 pounds or more, depending on the circumstances. Ordinarily, direct-acting pumps are furnished, their exhaust being delivered to the evaporator. The condenser often can be so placed as to draw its own water by suction.

MILLING OPERATIONS

The milling operations outlined below are generally involved only in the preparation of the grades of salt used on the table and in the dairy. The character of the grains of such salt is shown in Plate XXII. The salt is allowed to remain in the storage bins until it is thoroughly cured. The longer it remains in storage the less heat is required in subsequent drying. The centrifugals now used at many plants for the purpose of removing the brine and bittern from the salt crystals before storage are highly efficient and practically obviate the necessity of subsequent drainage and storage. Where a coarser grade than vacuum-pan salt is used for making table or dairy salt it may have to undergo a preliminary crushing.

After the removal of as much moisture as possible in the centrifugals or bins the salt is removed to the drier. This is a rotary cylinder which revolves slowly and is provided with steam pipes or a steam jacket or other equipment that heats the salt to a high temperature during its slow passage through the machine. At the front end of some driers there is an auxiliary steam coil and a blower to force in hot air and at the same time to blow out the lighter impurities, principally gypsum and moisture. Great care is exercised to prevent the dust from becoming disseminated in the plant, it is collected in an air-tight room and barreled. A fan at the rear end of the drier assists in the elimination of the gypsum, dust, and moisture. The salt after it has passed through the drier may contain as little as 0.1 per cent moisture.

The salt from the drier (Pl. XXIII, A) is passed through screens (Pl. XXIII, B) to remove lumps and to assort the grains for the trade. Cylindrical wire-mesh screens, shaking screens, or bolters are used. The grains of various size are deflected into hoppers and thence to bins. At some mills the salt is run from the bins to automatic weighing machines and into the cartons in which it appears in the trade. To render certain grades of table salt moisture proof and to make them run as freely as possible, a small amount—usually not more than 1 per cent—of some nonhygroscopic substance like magnesium carbonate is used to coat the grains.

The effort throughout the entire process in up-to-date establishments appears to be to take advantage of labor-saving devices. The salt is moved by hand as little as possible, screw conveyors, elevators, and other mechanical devices being adopted wherever practicable. The details of final manipulation are so varied at different establishments in the United States that only the general practice has been outlined.

COMBINATION SALT.

Most salt produced by the grainer process has a loose, light, flaky texture, though its character may be varied by varying the temperature and hence the rate of evaporation at which it is produced. If sufficiently high steam pressure is maintained, a rapid ebullition follows and the salt is granular. If the temperature is low, evaporation takes place chiefly from the surface of the brine and the salt is flaky or flocculent. In other words, the slower the rate of crystallization the larger the grain of salt. As grainer salt has certain characteristics for which there is considerable demand, and as it must be made slowly in order to produce a coarse grain, it commands a comparatively high price. The salt produced in the vacuum pan is a fine-grained or granular salt. "Combination salt," as the name suggests, is a product formed by combining the salt made by the two processes.

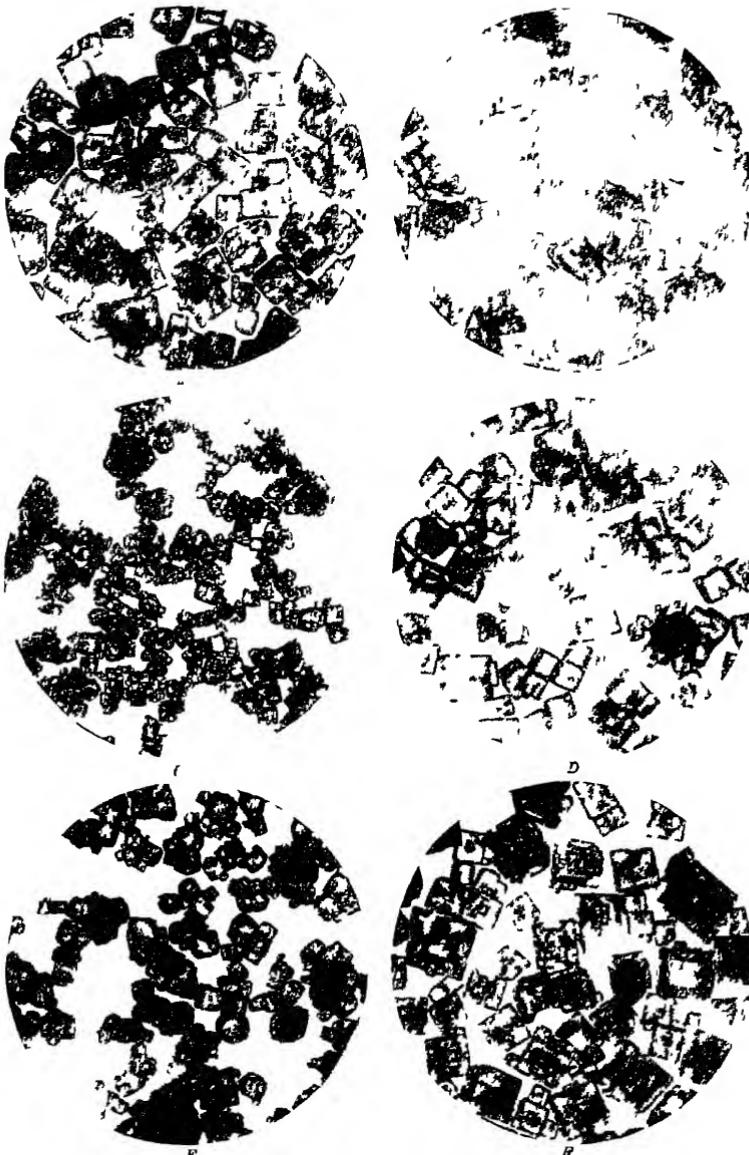
According to the process of making combination salt devised by Lillie^a the brine is evaporated in the vacuum pan in the usual manner, and the salt crystals formed fall to the lower part of the conical chamber below the steam tubes. The salt is then carried with brine under pressure through a pipe to the grainers in operation making grainer salt. The vacuum-pan salt, having been introduced into the grainer, falls to the bottom at the rear end of the grainer and is moved forward by the usual mechanical devices. The salt produced by evaporation in the grainer also settles to the bottom, where it comes in contact with the vacuum-pan salt. While the fine salt from the vacuum pan moves forward in the grainer it is subject to the action of the hot brine and to contact with the salt made in the grainer, and a combination grain that differs in character from that of both vacuum-pan and grainer salt is produced. The particles of solid salt probably afford centers of crystallization in the saturated brine.

The product is not simply a mixture of crystals of various texture but is uniform and peculiar in texture. The identity of the fine salt from the vacuum pans usually is quite lost and the product approaches in its physical character the salt made by the open-pan or the grainer process. The character of the combination salt may be altered by varying the proportions of vacuum-pan and of grainer salt, and many different grades of salt may also be made by varying conditions in the grainers.

COMMERCIAL STATUS OF PROCESSES.

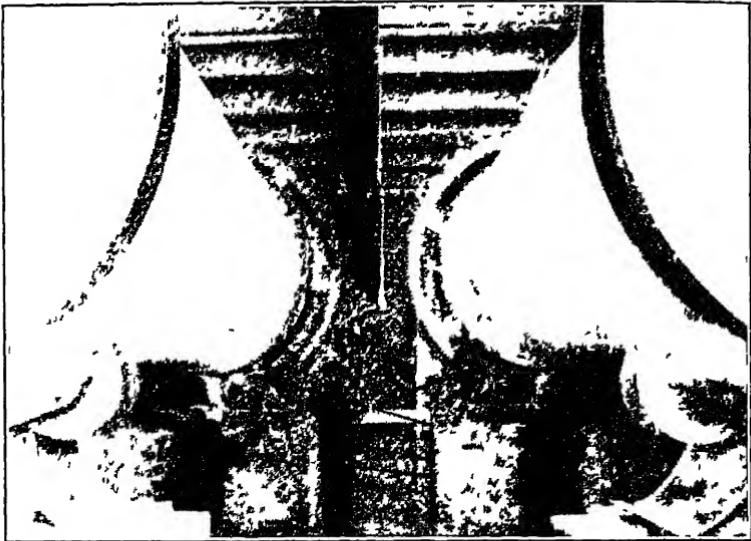
The wear and tear incident to the operation of all salt-making machinery is heavy. Moreover, if a salt block is allowed to be idle for a year it becomes almost ruined, consequently, it is often cheaper to make salt for a season without any profit than to shut down.

^a Lillie, S. M., U. S. Patent No. 988002, dated Mar. 28, 1911.



MARKET SIZES OF SALT MAGNIFIED 18 DIAMETERS

.*A*, Salt made in a triple-effect Manistee vacuum pan by the Hutchinson Salt Co., Hutchinson, Kan.; *B*, Salt made by the Alberger grainery process Diamond Crystal Salt Co., St. Clair Mich.; *C*, Salt made in the Lillie quadruple effect evaporator, San Francisco Salt Refinery Co., San Francisco Cal.; *D*, Salt made in a single effect vacuum pan, Worcester Salt Co., Silver Springs N. Y.; *E*, Salt made in Lillie evaporating apparatus, Carey Salt Co., Hutchinson, Kans.; *F*, Salt made in a quadruple-effect vacuum pan, California Salt Co., San Francisco, Cal.



1 ROTARY CYLINDER DRIER USED IN DRYING HIGH GRADE SALT



TYPE OF SCREEN USED AT MANY SALT PLANTS IN UNITED STATES NOTE SCREW CONVEYOR AT BASE FOR REMOVING THE SALT

Apropos of this rapid deterioration, the following quotation from a letter of a practical salt maker of northern Ohio to the writer is worthy of careful consideration

Another difficulty in fixing the exact costs is this. That in figuring costs and basing selling prices thereon, some salt producers do not provide for very rapid deterioration of salt-making apparatus, and it is unfortunate on that account and also on account of overproduction that many hundreds of thousands of dollars have been lost by salt producers in recent years

The factor of overproduction is one for deep consideration by the manufacturers of salt in the United States. During the work of the writer in the different salt fields of the country, especially in the Eastern States, during 1911 and 1912, the consensus of opinion seemed to be that a great deal more salt was being produced than could be marketed, estimates of the overproduction ranging from 20 to as high as 50 per cent. The facts that large up-to-date plants at many places were not working at full capacity and that some were working only half time or at half capacity, while others were temporarily closed awaiting a better market or closed with no apparent prospect of reopening, present a significant situation to those planning to enter the business. According to one operator, "if the demand were doubled at present (Sept 15, 1911) there would be ample apparatus in the United States to care for it and for a large surplus on hand." This operator spoke presumably of the eastern half of the United States, and the plant that he was connected with was working at only half its capacity. A similar situation must have existed some 30 years ago, for in 1888 Chatard^a said "The present plants are able to furnish a supply much larger than can find a fairly profitable market." He began his report on salt-making processes in the United States, with the following statement

The various elements which go to make up the cost of an article of commerce are found exemplified in the simplest and clearest manner in the salt industry. The raw material, the brine, has no other value than that given it by the cost of sinking the well and pumping, the fuel used is, so far as practicable, unsalable refuse, the machinery is of the simplest character, there being but little opportunity for the use of labor-saving devices, manual labor, mostly of a comparatively unskilled character, is almost exclusively employed, and the handling, transportation, and distribution of the product are effected in the cheapest manner, the foreign article being to a large extent brought in as ballast and sold at rates but little above those at the port of shipment.

Great changes have been wrought in the salt-making industry in 25 years and it is interesting to contrast the present (1915) situation with that existing when Chatard's paper was written. It is doubtless still true that the brine, the raw material from which all the evaporated salt is obtained, has no other value than that given it by

^a Chatard, T. M., Salt-making processes in the United States U. S. Geol. Survey Seventh Ann. Rept., 1888, p. 497

the cost of sinking the well and pumping the brine. But brine salt constitutes only 78 per cent of the total salt produced, as will be observed from the following table, and the cost of the preliminary work connected with mining the remaining 22 per cent is considerable.

Production and value of rock and brine salt in the United States in 1915

Material	Short tons	Value
Rock salt	1,165,387	\$2,299,894
Brine salt	4,187,023	9,447,792
Total	5,352,410	11,747,686

In contrast with Chatard's statement regarding the use of unsalable refuse fuel are the following comments by Willcox ^a:

There is now going on in the salt industry, especially in Michigan, a transformation almost as radical as occurred when Michigan lumber first brought out Michigan salt. It is a change from the sawmill system of producing salt, in which fuel economy was no object, to a time that is almost here when fuel will be the main consideration. To illustrate what such a change means, refer to the early days when the Onondaga salt district in New York was the leading producer in the country. When the enormous Michigan production began to affect the eastern salt districts it hit the Onondaga district very hard, as can be inferred from the report published in 1877 of the superintendent of the Onondaga Salt Springs:

The business of manufacturing salt for the past season has been one of great embarrassment, owing to the general depression of business throughout the country and the consequent low prices afforded for the manufactured article, a result always incident to any market where the supply is largely in excess of the demand.

Another and, perhaps, more serious embarrassment grew out of the fact that a very large supply of salt has been furnished at the Saginaw saline. These works are, and must continue for many years to be, a vigorous competitor with our own.

So long as Saginaw continues the great center of a gigantic lumber trade, so long will she be a standing competitor in the production of salt. The refuse of her sawmills is estimated to be sufficient for the annual manufacture of 12,000,000 bushels of salt. During the past year her product has swollen to the enormous sum of 8,000,000 bushels. This refuse would be totally valueless for any other use than as fuel for the manufacture of salt. In fact, it would be a nuisance to the lumber dealers, because it would subject them to the expense of carting it from their works and destroying it.

This furnishes to Saginaw, without charge, what is to us the main factor in the cost of our product.

Thus it is evident that the old conditions have undergone great changes, and the time is in sight if not actually here when the salt industry, which has been a side issue, connected with the lumber business in certain parts of the Lower Peninsula of Michigan, must either stand on its own feet or pass altogether. Changing conditions already have brought about certain readjustments which must go forward to keep pace with the changing conditions in the lumber business if the salt industry, depending on the refuse from lumber mills, is to survive.

In the character of the machinery, the quality of labor, and the use of labor-saving devices there have been profound changes since the date of Chatard's commentary. The remarkable development of mechanically raked grainers and the establishment of the vacuum-pan process are indications of the advancement along such lines. In some of the modern grainer and vacuum-pan plants the salt is not touched by the human hand from the time it crystallizes from the brine until it is ready to be wheeled on board the cars. The character of the labor naturally, instead of remaining purely manual, has un-

^a Willcox, G. B., Evaporation tests of a salt grainer Michigan Eng. Soc. for 1907, 1907, pp. 164-189.

designed a complete change as more complex machinery has been adopted, until a large proportion of the work in the modern plants requires mechanical skill of an advanced type and the chemical engineer is called frequently into conference. All these improvements have tended toward increased efficiency and the production of a high-grade article at as low price as is compatible with the existing demand for high quality.

REMOVAL OF GYPSUM FROM BRINES

One of the gravest difficulties encountered in salt making is the removal of gypsum. In practice the terms gypsum and plaster are both employed to designate the scale formed during the concentration of brines. The writer is not aware that the exact composition of the scale is known, it may correspond to the hemihydrate, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$. Chatard suggests several methods for its separation, but at most plants the old method of stopping the process and scaling the gypsum is still employed. One of the reasons for this adherence to laborious cleaning is that any chemical treatment that effectually rids the brine of calcium sulphate, lime, magnesia, and oxide of iron is generally too expensive to be practicable, and, consequently, if used at all must be confined to the high-grade table and dairy products. Lime is almost universally used to remove iron, though sodium carbonate (soda ash) is used in some localities.^a

In the Alberger process the principle of superheating the brine at high pressure and releasing the pressure, thus effecting precipitation of the gypsum, is practiced. This is in line with a suggestion by Chatard^b that "in default of a chemical precipitant we are compelled to consider the application of heating alone as giving any reasonable prospects of improvement." He also called attention to the rapid separation of calcium sulphate near the point of saturation and at temperatures above 212° F and suggested that the deposition of the sulphate and the recrystallization of the salt should, if practicable, be separate processes and that the apparatus to be used for the former process should be specially constructed to facilitate scaling. It is not yet established whether the separation of gypsum in this way is more efficient or cheaper than its removal by ordinary precipitation on the bottom of the open pan or the grainer pipes or in the flues of the vacuum pan, with the consequent labor and loss of time incident to scaling. The Alberger process is in limited use as compared with the other methods of making fine-grained No. 1 salt.^c

^a See patents issued to Charles Glaser and G. J. Muller on processes of refining salt. U. S. Patents Nos. 957416 (reissued as 13268), and 957417.

^b Chatard, T. M., Salt-making processes in the United States, U. S. Geol. Survey Seventh Ann. Rept., 1888, p. 502.

^c Persons interested in this problem will find many data and references to domestic and foreign literature in Chatard, T. M., Salt-making processes in the United States, U. S. Geol. Survey Seventh Ann. Rept., 1888, pp. 497-527, also in Cameron, F. K., and Bell, J. M., Calcium sulphate in aqueous solutions, Bull. 92, U. S. Geol. Survey, 1896, 71 pp.

RELATIVE EFFICIENCY OF PROCESSES.

Comparatively little has been published regarding the efficiency and economy of salt-making processes. According to Merrill,^a a kettle block can produce 2,520 pounds of salt from 67° brine (salimeter reading) for each ton of anthracite dust used as fuel, and 4,088 pounds from 96° brine, these figures corresponding to evaporation efficiencies of 5.83 and 6 pounds of water per pound of fuel. Chatard,^b selecting the best results of the various systems, concludes that 1 pound of coal evaporates 5.72 pounds of water in the direct-heat open-pan process, 6.47 pounds of water in the high-pressure grainer process, and 7.69 pounds in the low-pressure grainer process followed in the Kanawha district (see pp 77-79). Willcox^c calculates from the results of a careful run in a Michigan grainer an evaporation efficiency of 8.322 pounds of water per pound of coal. So many factors, however, affect such statements of efficiency that the figures quoted are unsafe criteria for comparison. The concentration and composition of the brine, the nature and heat value of the fuel, atmospheric conditions, and other conditions make analysis of the problem difficult. Ease of operation, low cost of maintenance, dependability, simplicity of construction, and means of meeting and overcoming unexpected difficulties are among the factors that give an evaporator the best all-round efficiency. An attempt was made by the writer to procure new data on the unit cost of making salt, but so few and so diverse replies were received that compilation or comparison was impracticable, and consequently this phase of the industry has necessarily been left for consideration at some future time. It is greatly to be hoped that salt manufacturers may publish data relating to this subject.

The experiments by Willcox,^d to which reference has been made, represent so extensive an analysis of the grainer process that his report of the results of them have been abstracted. The test was run in Michigan under normal working conditions on a grainer equipped with submerged mechanical rakers and heated by exhaust steam that entered at an average temperature of 216.6° F., and had an average quality of 97 per cent. The grainer was 143 feet long and 10.67 feet wide at the average level and was filled with brine to an average depth of 1.229 feet. It contained 1,072 feet of 3.5-inch pipe, the ratio of the evaporating (grainer) area to the heating surface being 1.34. The brine at 92.5 per cent saturation was run into the grainer at a temperature of 71.6° F. and the test was continuous for 192

^a Merrill, F. J. H., Salt and gypsum industries of New York. N. Y. State Mus. Bull., vol. 3, No. 11, 1893, p. 65.

^b Chatard, T. M., Salt making processes in the United States. U. S. Geol. Survey Seventh Ann. Rept., 1886, p. 526.

^c Willcox, G. B., Evaporation tests of a salt grainer. Michigan Engineer, 1907, p. 104.

^d Willcox, G. B., place quoted.

hours, at the end of which time the saturation of the bittern unduly impeded evaporation. At the start, evaporation was continued till the level of the brine had lowered nearly to the steam pipes in the grainer. The quantity evaporated was then restored by introducing new brine, and this process of alternate evaporating and filling was continued throughout the test. The results of the run are summarized in the following tables.

Results of operating a grainer in Michigan for 192 hours

Item	Pounds
Total production of hot salt	110,950
Production of hot salt per hour	577.8
Equivalent in seasoned packed salt per hour	4534.5
Total condensation of water from grainer pipes	110,368
Condensation per hour	2,137
Equivalent condensation of dry steam per hour	52,073
Production of hot salt per square foot of grainer surface	72.7
Production of hot salt per square foot of heating surface	97.9
Production of hot salt per linear foot of 3-inch steam pipe.	102.5
Production of hot salt per cubic foot of brine	13.48
Condensation of dry steam per cubic foot of brine	46.8

Volume of steam condensed and quantity of hot salt produced during successive periods of approximately uniform production

Duration of period	Total during period		Rate per hour during period		Steam required to produce 1 pound of hot salt
	Hot salt produced	Steam condensed	Hot salt produced	Steam condensed	
Hours	Pounds	Pounds	Pounds	Pounds	Pounds
9	(a) 26,320		2,924		
37	29,207	91,354	2,466		3.605
53	32,968	110,570	2,033	2,038	3.348
17.5	11,783	39,295	673	2,245	3.336
34.5	20,896	60,386	605	2,008	3.01
4	2,468	7,594	617	1,898	3.076
24	10,640	45,453	443	1,477	3.18
13	6,900	24,040	531	1,849	3.49
192	114,950	414,012			

a Production sufficient only to fill the "clearance" on the bottom of the grainer

Willcox^c calculates that the efficiency represented by these figures corresponds approximately to the evaporation of 8322 pounds of water by 1 pound of coal. He adds that in the usual operation of this grainer the bittern is replaced by new brine every 5 days, 2 hours being lost at each filling, and that the services of 4 men for 3 hours are required to scale the pipes every 30 days.

a One pound of hot salt is equivalent to 0.925 pound of seasoned packed salt

b The steam contained 3 per cent moisture

c Willcox, G. B., place quoted

TECHNOLOGY OF MINING AND MILLING OF ROCK SALT.^a

SITUATION AND DEVELOPMENT OF MINES

Rock salt was first discovered in North America, so far as is known, at Petite Anse, La., in 1862, and it is still mined there and also at Grande Cote, near by. Though its existence in New York and Michigan has been known for many years, it is mined in New York only by the Retsof Mining Co., at Retsof, and the Sterling Salt Co., at Halite, and in Michigan only by the Detroit Salt Co., at Detroit.

The beds of rock salt in Kansas were discovered in 1887 and 1888, during drilling operations for oil and gas, at Ellsworth, Lyons, Hutchinson, Great Bend, Kanopolis, Sterling, Kingman, Anthony, and Wellington. The salt-bearing series ranges in thickness from place to place from 50 to more than 400 feet.

Rock salt in Kansas has been produced, to any extent, at only five mines, and these have been operated by the Kingman Salt Co., Kingman, the Crystal Rock Salt Co., The Independent Salt Co., and the Royal Salt Co., at Kanopolis, and the Bevis Rock Salt Co., at Lyons. In 1915 the four companies last named were engaged in active mining. The Bevis Rock Salt Co. began to hoist salt in 1890 and has been operating continuously since. The shaft of the Royal Salt Co. was sunk in 1891, the mine has been operated only part of the time since then, but at present it is being worked. The shaft of the Crystal Rock Salt Co. was sunk in 1908, and the mine has been in operation since. The first production of the Independent Salt Co. was in 1914. Shafts have been started at Ellsworth, Marquette, and Little River, but for various reasons the work has been abandoned.^b

RETSOF MINING CO., RETSOF, N. Y.

MINING

The shaft of the Retsof Mining Co., Retsof, N. Y., is 1,017 feet deep, and it passes through the following beds:

Section of main hoisting shaft No. 1, Retsof Mining Co., Retsof, N. Y.

Material	Thickness, feet	Depth, feet
Shale	133	
Limestone.	8	141
Shale	232	373
Limestone	4	377
Shale	23	400
Lime	3	403
Corniferous limestone	142	545
Cement	13	558

^a The descriptions are based on observations made in 1911. The writer has not had any opportunity to visit the field and to verify them since that year.

^b Young, C. M., Rock salt mining operations in central Kansas. *Mining World*, vol. 34, 1911, p. 1223.

Material	Thickness, feet	Depth, feet
Sandstone	1	562
Cement..	7	569
Sandstone	14	563
Gypsum..	4	587
Cement ..	26	613
Gypsum	47	660
Magnesian lime and sands	63	723
Cement	14	737
Blue shale	25	762
Cement.	10	772
Blue shale	12	784
Helderberg cement	17	801
Mixture.	31	832
Cement	10	842
Lime, cement, and sand	15	857
Cement	6	863
Blue shale	19	882
Red shale	12	894
Blue shale	41	935
Red shale	5	940
Blue shale	12	952
Lime	12	964
Salt and shale ..	32	996
Foot of shaft		1,017

The salt bed that is being worked is 8 feet thick, but rolls pinch it to a thickness of 5 feet locally. Great care is exercised not to break into the roof or to pick up the floor. Drilling is done with 1½-inch auger drills, operated by 3½-horsepower electric motors. The rooms are run 30 feet wide, and the net result of the mining is the removal of five-ninths of the salt, leaving four-ninths standing as square pillars, each side of each pillar being 30 feet long. The drilling is done at the room face, the end of the room being advanced in the form of a blunt wedge. The walls of the room are, of course, kept parallel during the advance of the mining. The salt is hauled by mules from the room face to the sidings but electric haulage is used from the main headings to the shaft. Mule power is used also for loading the salt into the cages.

MILLING

The salt is hoisted in 3-ton mine cars from the foot of the shaft to the top of the mill, where the run-of-mine salt is dumped on grizzly or middle bars made of cast steel and arranged in tiers. The finer salt falls through the grizzlies into a hopper, and most of the coarser part is crushed between large rolls though part of it is carried by conveyers to a storehouse, from which it is loaded on cars for shipment. The pieces of salt as they come from the mine are 1 foot or less in diameter. The subsequent operations consist of alternate screening and crushing, by which the desired market sizes are obtained.

Four market sizes are produced in New York in addition to the large lumps direct from the mine. These, beginning with the coarsest, are known as No 2, No 1, Coarse C (common coarse, indicated by the letters "C C"), and Fine C (common fine, indicated by the letters "C F"). These grades are illustrated in Plate XXIV (p 130).

STERLING SALT CO., HALITE, N. Y.

The shaft of the Sterling Salt Co., at Cuylerville or Halite, N. Y., is approximately 1,150 feet deep. After the salt has been mined it is lifted in a 3-ton automatic dumping cage to the top of the mill and dumped on sets of grizzly bars. The fines drop through one set and the lumps drop through another set to crushers, and the larger hard lumps that are salable descend through a zigzag chute to be loaded for shipment. The fines from the crushers and from the grizzlies pass through the main hopper beneath the grizzlies to three shaking screens, arranged in decks, one screen above another, with the coarsest at the top.

The material that does not pass through the coarsest screen is diverted through a spout to a picking table (size 4). The material that passes through the first screen and over the second goes to a picking belt (size 3), where impurities are removed. Sizes 3 and 4 are not salable and are therefore crushed together and returned to the main hopper by a bucket conveyor. No 2 grade is what passes through the upper two decks of the head screens but not through the third deck. The finer grade, which passes through the third deck of the head screen, is a mixture of No 1, C C, and C F. This mixture is conveyed on belts to the tail screens. From the conveyor belt it is dropped into a hopper and thence diverted in spouts to tail screens. There are two decks to each set of these screens. The salt that fails to pass through the upper deck is known as grade 1, that which passes through the upper deck but does not pass through the lower deck is grade C C, that which passes through both screens is grade C F. The operations of this mill are graphically shown in figure 9.

DETROIT SALT CO., DETROIT, MICH.

MINING

The shaft of the Detroit Salt Co., Detroit, Mich., is 1,050 feet deep, with a 20-foot bed of salt at the bottom, of which 16 feet are worked by the room-and-pillar system, the rooms and entries being 35 feet wide and the pillars 40 feet square. The shaft is divided into three compartments, two of which are used for hoisting and one for supplying air, the foul air being removed through the hoisting compartments. The entire shaft is 9 by 18 feet, and in its present working condition each compartment is 5 by $5\frac{1}{2}$ feet.

MILLING

After the run-of-mine salt has been hoisted to the top of the mill the large lumps are conveyed to a storehouse for shipment. The fines and smaller lumps go through a grizzly and two toothed crushers. The fines are then removed by a screen and separated into four

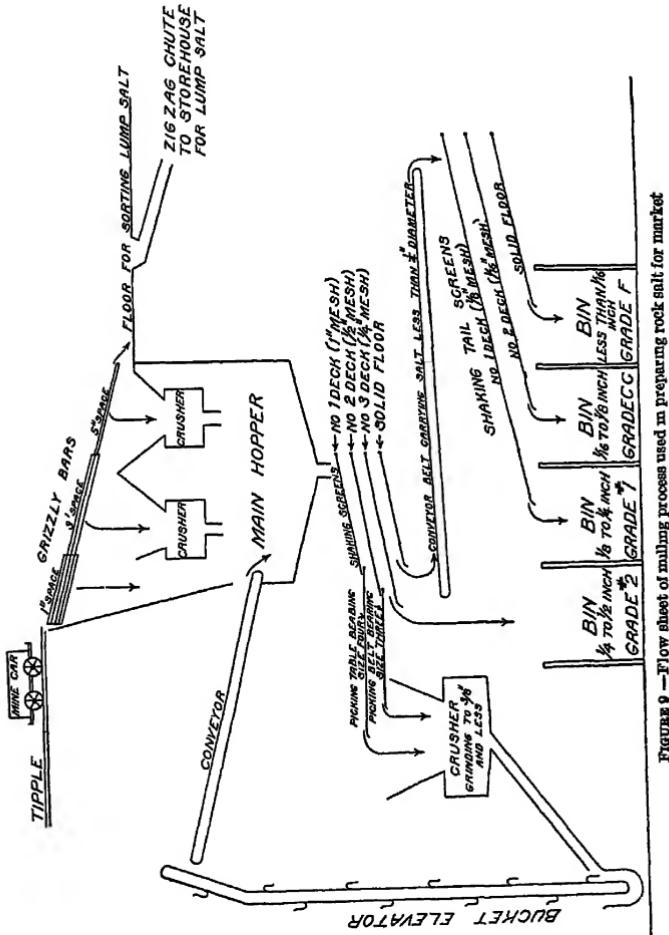


FIGURE 9.—Flow sheet of milling process used in preparing rock salt for market

marketable sizes (No 2, No 1, C C, and C F grades). The oversize material is picked to remove foreign material and discolored salt. This oversize material, constituting about 70 per cent of the run, is then crushed between corrugated rolls and elevated to another screen, and the four marketable sizes are again separated. The

a room are fired simultaneously by electricity. The blasts are large, 500 tons of rock often being shot down at one blast. The salt is loaded into mine cars and hauled to the shaft by mules.

The salt seam mined is 18 feet thick and is closely uniform. About 6 inches of it are left as a floor and 12 to 18 inches are left as a roof. Thus the mine has a solid salt floor and roof and no shale has to be picked out of the salt. The seam dips southwest, but the dip is so slight that the workings are considered level. About 3 to 4 acres are mined out each year.

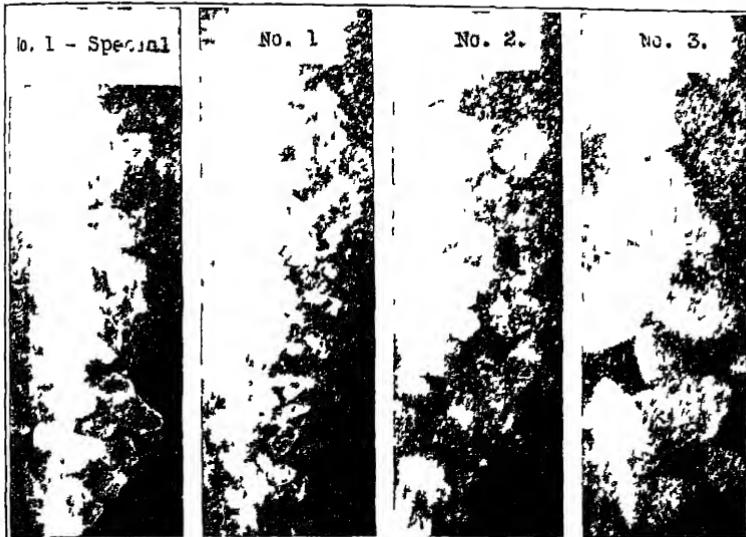
MILLING

The company has two mills, both being used only when a large output is demanded. As the mills are alike, a description of one suffices. The salt hoisted from the mine is dumped from the cars into a hopper and is fed through a gate between toothed rolls. The large lumps are prevented from going to the rolls by bars over them and are diverted through a chute to a storeroom. After the salt has passed between the rolls it goes to a shaker, through which the fines pass. The oversize material goes to a set of corrugated rolls and from them the salt goes to a pair of shakers, which divide it into four grades, oversize, No. 2, No. 3, and C F. The C F salt is elevated to a pair of impact screens, by which it is divided into grades 1, 7, and 4, which go to the bins. Grades 2 and 3 also go to the bins and the oversize goes back to the rolls to be reground.

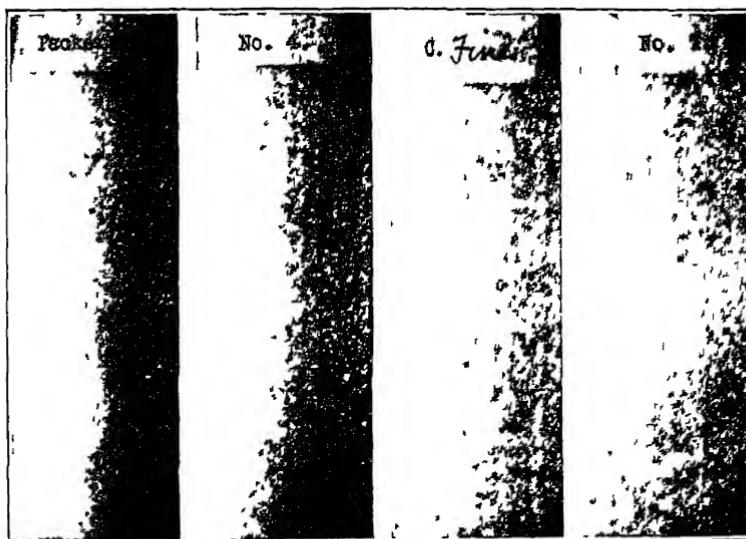
A small portion of the C F grade is sent to a centrifugal "cyclone" crusher, and the crushed product is sent to a pair of revolving screens. The oversize is mixed again with the C F salt and the fine salt, or "packers' fine," is sent to the bins. The other sizes may also be ground in the centrifugal crusher, and it is customary to grind sizes of salt for which there is little demand into packers' fine.

EQUIPMENT

The mine is equipped with five boilers fired with fuel oil, about 600 horsepower is necessary to run the plant, the mill being operated by a 150-horsepower Corliss engine. The hoisting is done with a straight-line Litchfield hoist, the speed being about 2,650 feet a minute. The drum is flat, the cable is steel, $1\frac{1}{2}$ inches in diameter, and the sheave wheels are 8 feet in diameter. The compressed air for the mines is furnished by a large two-stage Ingersoll-Sargent compressor and is delivered to the mining machines at about 100 pounds pressure. The mine fan, which is an 18-foot exhaust fan of the Guibal type, is operated by an independent steam engine. The mine has a capacity of about 1,000 tons a day, but 700 tons of salt is about the daily maximum hoisted.



A COARSER GRADES OF ROCK SALT PRODUCED IN KANSAS ROCK SALT MINES GRAINS ABOUT
SIX SEVENTHS OF ORIGINAL SIZE



B FINER GRADES OF ROCK SALT PRODUCED IN THE KANSAS ROCK SALT MINES ABOUT
SIX SEVENTHS OF ORIGINAL SIZE

ROYAL SALT CO., KANOPOLIS, KANS

The shaft of the Royal Salt Co (Pl X, C, p 52), constructed in 1890, is about one-quarter mile from Kanopolis, Ellsworth County, Kans. In 1912 water was being pumped from a ring in the shaft at a depth of 210 feet. The timbers of the shaft are held in place by a series of props to the side walls of the area where the salt has been washed away, and the timbering has been tied together with flooring. The shaft contains two hoisting compartments, each 5 5 by 6 5 feet, and an air compartment 8 by 6 5 feet, and it is 803 feet deep. The bed of salt mined is 9 feet thick.

MINING

Two main entries 40 feet wide have been driven north and south, and the mine is worked on a three-heading system, with all entries the same width. Compressed-air auger drills are used and 9-foot holes are bored. No undercutters are used and the salt is blasted off the solid. The powder used is a 20 per cent nitroglycerin powder, and it is exploded by electricity. As the roof and floor are tough gray shale, no timbers are deemed necessary.

The salt is loaded into mine cars holding 1 ton to 1 5 tons. The cars are hauled to the shaft by mules and hoisted to the top of the mill placed over the shaft. The seam of salt is uniform to the west and south, but not so much so to the east and north. It dips north-east in one part of the mine, but the dip is not great enough to hinder hauling.

MILLING

Eight grades of salt are made in the mill. Nos 1 special, 1, 2, 3, 4, 7, C F, and packers' fine. Lump salt is also sold. These grades are like those illustrated in Plate XXIV.

The salt is dumped at the top of the mill onto a set of bars and all fine salt passes through to a 3-screen shaker. The large lumps may go by the lump conveyor to a storeroom or between 24-inch by 30-inch toothed rolls. From the rolls it goes between a second pair of toothed rolls, set closer together, and from that pair it goes to three fine-screen shakers. The shakers are narrow and contain wire screens, whereas those at the Bevis mill are wide and have punched-plate screens. The products of the shakers go to bins and elevators. There are also three fine grinders, and grades 2 and 3 are fed to them when there is a demand for fine salt from these grinders, being screened and then binned. The mill can handle about 250 tons of rock salt a day.

EQUIPMENT

The plant has one sacking room and a lump storeroom. The steam for the hoisting engine, compressor, mill engine, fan engine,

and pumps is furnished by five oil-fired boilers of 100 horsepower each. The hoisting engine is a Vulcan hoist with a conical drum 7.5 feet in diameter at the small end and 10.5 feet in diameter at the middle. The 16-inch by 18-inch single-stage Ingersoll compressor delivers air at 100 pounds pressure. The mill is operated by a Buckeye Corliss engine of about 100 horsepower. An exhaust fan over the air shaft is operated by a separate steam engine.

CRYSTAL ROCK SALT CO., KANOPOLIS, KANS

THE SALT BED

The salt bed that is worked by the Crystal Rock Salt Co. at Kanopolis, Kans., is 11 feet thick and is capped by a layer of shale one-eighth inch thick. The bed is about 170 feet below the top of the first salt bed encountered in sinking the shaft, as will be seen from the following section.

Section of salt beds above the rock salt mined by the Crystal Rock Salt Co., Kanopolis, Kans.

Material	Thickness Ft In	Depth Ft In
Unrecorded strata to top of salt	(612)	
Salt with black flakes, quite dark	10	
Shale.	1	11
Fair salt.	3	14
Salt mixed with shale.	4	18
Fair salt with dirt	6	24
Parting shale	0 2	24 2
Fair salt	5	29 2
Shale	1 6	30 8
Salt and dirt mixed	6	36 8
Dirt.	0 3	36 11
Fair salt	3 6	40 5
Shale	0 2	40 7
Good salt	4	44 7
Shale..	1	45 7
Salt and shale mixed.	4	49 7
Fair salt.	4	53 7
Black flakes and salt mixed	20	73 7
Shale	0 8	74 3
Dirty salt	7	81 3
Shale .	1	82 3
Fair salt	3	85 3
Shale	1 6	86 9
Fair salt.	2	88 9
Shale.	2	90 9
Dirty salt	11	101 9
Shale	1	102 9
Fair salt	3	105 9
Salt and shale mixed	0 10	106 7
Clay	7	113 7
Salt and shale mixed	9	122 7
Hard black salt	0 8	123 3
Good salt with black streaks running up and down	8	131 3

Material	Thickness		Depth	
	Ft	In	Ft	In
Fair salt	4		135	3
Salt and shale mixed	1	6	136	9
Fair salt with dark streaks	6		142	9
Shale ..	1		143	9
Dark salt	7	6	151	3
Purting	0	1	151	4
Dark salt	1	3	152	7
Purting	0	1	152	8
Dark salt	1	6	154	2
Good salt	3		157	2
Black salt	0	6	157	8
Fair salt	5	6	163	2
Shale	0	2	163	4
Good salt	1	8	165	
Fair salt	3		168	
Streaked black salt	2	6	170	6
Salt (now being worked)	11		181	6

The section does not show the entire thickness of the salt-bearing series, as a prospecting shaft known as No 3 shaft has been sunk nearly 50 feet deeper in the search for potash salts. The section revealed by this deeper shaft is given below.

Section of Shaft No 3, Crystal Rock Salt Co, Kunopolis, Kansas

Material	Thickness		Depth	
	Ft	In	Ft	In
Shale ..	0	10	-	
Dark salt	5		3	10
Shale	0	2	6	
Dark salt	1	10	7	10
Shale	0	1	7	11
Dark salt mixed with shale	15		22	11
Shale	0	1	23	
Dark salt	1	4	24	4
Shale	8		32	4
Dark salt	4		36	4
Shale	0	1	36	5
Light-colored salt.	3	6	39	11
Shale	0	1	40	
Light-colored salt	6	10	46	10

Thus if the thickness of the salt bed that is being worked is taken as 11 feet the total thickness of salt and associated beds is about 228 feet, and the sections given above do not include the entire saline series. Of the sections given above, 188 feet 11 inches is salt designated as fair, good, dirty, or mixed with other ingredients. The shaft was sunk in 1907 and 1908. It is about one-quarter mile southwest of that of the Royal Salt Co.

METHOD OF SINKING SHAFT

The shaft is a three-compartment shaft, 6 5 by 18 feet inside dimensions, two of its compartments being used for hoisting and the

third for an air shaft. The shaft was timbered down to the first water level with heavy timbers, and a large drum of boiler iron, the shape of the shaft, was driven through the water-bearing sand. The drum is bracketed and timbered on the inside to prevent its collapsing. It was driven into a seam of clay below the sand, and the shaft below the clay seam is timbered with heavy timbers set "skin to skin." Two other small water-bearing strata were encountered and a water ring was inserted at a depth of about 300 feet, from which water is being pumped.

The shaft is 800 feet deep and strikes the same seam of salt as that mined by the Royal Salt Co. The workings extend only a few hundred feet from the shaft.

MINING

The mining operations are similar to those in the Royal mine. Electric drills were tried but they did not prove satisfactory and compressed-air auger drills are now used. The mine cars hold 2 tons and are trammed by hand.

MILLING

The milling processes are similar to those in the mill of the Royal Salt Co., the main differences being that the Crystal mill is double, the cages are self-dumping, and the machinery is more compact. The same grades of salt are made. About 600 tons of salt can be crushed in a day with both mills running, but in 1912 only one mill was operated, and about 250 tons of salt was ground daily.

EQUIPMENT

The mine has one sacking room below the bins and a lump store-room. The plant has three coal-fired boilers of 100 horsepower each, and all of them are used when the plant is in operation. The hoist is a direct-connected Crawford hoist with a cylindrical drum, the hoisting speed is 2,500 feet a minute. The compressor is a single-stage, belt-driven machine. A direct-current generator is used when the electric drills are operated. The mill, compressor, and generator are operated by a steam engine. No fan has been put in as the mine has been operated for only a short time.

COMMERCIAL GRADES OF KANSAS ROCK SALT

The same grades of salt are produced at all the mines in Kansas and are given the same names in different parts of the State. The principal grades are numbered 1, 2, 3, 4, 7, C F (common fine), packers' fine, and lump salt. Grade No. 2, of which most is sold, is composed of cubes one-eighth to one-quarter inch in diameter and is extensively used for making brines in packing houses and for salting hides. Grade No. 1 consists of grains about the size of grains

of wheat This salt is also used for salting hides, in manufacturing soda ash and caustic soda, in making brines and freezing mixtures, and in soap making Grade No 3 is coarse, the grains being more than one-quarter inch in diameter This salt is used in refrigerator cars and in other refrigerators Grade No 4 is about as fine as coarse evaporated salt, and it is used by stockmen, soap makers, and glass manufacturers and also in chlorination furnaces Grade C F contains all grades from No 1 to the coarsest and it is used for about the same purposes as No 1 Packers' fine is the finest grade made It can be used for domestic purposes and it is used extensively in packing beef and pork Lump salt is obtainable at all the mines, some lumps weighing several thousand pounds being sold Lump salt is gray and firm It is sold for salting live stock

MYLES SALT CO , GRANDE COTE, LA

According to Veatch^a salt was discovered at Grande Cote, La , in 1897, and nearly a year later the Myles Salt Co was organized The present shaft was commenced in July, 1898, where the salt is nearest the surface One hundred feet of 10-foot tubular casing was used in sinking the shaft to the salt In July, 1901, the work of sinking a rectangular shaft below this casing into the rock salt was begun The 600-foot level was reached and tunnels to the east and the west were being driven in March, 1902 The shaft is 645 feet deep The tubular casing was continued 10 feet into the rock salt The shaft was continued in cylindrical form 35 feet farther, and wood lagging inclosed by concrete a foot thick was used to prevent leaking. This structure was encircled at intervals by rings of asphalt 3 to 5 feet high and 2 or 3 feet thick at the base The surface of the salt after being thoroughly heated was painted with asphalt The shaft below the 135-foot cylindrical section is 10 feet square

Mining is carried on by first undercutting or blasting out triangular chunks of salt on a level with the floor of the mine The overlying layers are then removed in turn upward from the floor The salt is conveyed to the foot of the shaft in small dump cars drawn by mules over narrow-gage steel tracks At the shaft the salt passes through a crusher, from which it falls into a bin From the bin it is drawn off into a 5-ton self-dumping cage, in which it is drawn to the surface, the cage making the round trip in four minutes. A pair of 20-foot by 30-foot engines wind up the cable that lifts the cage Two compressors supply air to the drills in the mine, and a small separate engine works the ventilating fans The crusher at the bottom of the shaft, the screens, and the mill machinery above ground are run by electricity from a dynamo in the engine room The salt is ground after being dumped from the cage on the top

^a Veatch A C , General geology Louisiana Geol Survey Rept. for 1899, pt 5, 1899, p 125

floor of the building. It is then passed through screens of various mesh, depending on the sizes of salt marketed. Grades 1, 2, and 3 are used for refrigerating, curing hides, curing fish, making salt pickles, and glazing in enameling and pipe works.

The C (coarse) and F (fine) grades are used for dry-salting meats and clearing oleomargarine, and in chemical processes. The A grade is a special one, finer than No 1 and coarser than C. The D grade is also a special one, consisting of powdered salt from the grinding of any of the crushed grades in the mills, and it is used for any purpose where rapid solution is desired.

AVERY SALT MINING CO., PETITE ANSE, LA

Rock salt was discovered at Petite Anse, La., by John M. Avery, May 6, 1862, and so far as known this was the first discovery of rock salt in North America. The salt was first quarried in a number of open pits, which were destroyed in 1863. The first shaft, 8 feet square, was sunk in 1867 to a depth of 83 feet, the depth was later increased to 90 feet, 58 feet of which was in solid rock salt. After the ownership of the property had rested with different companies it finally reverted to the New Iberia Salt Co. in 1886, and arrangements were made for a switch to the plant from the main line of the Southern Pacific Co. Operations were continued until 1896, when the mines reverted to the Avery family, and two years later the Avery Rock Salt Mining Co. was formed. This company sank a shaft southwest of the old mine on a new site where operations are now conducted. According to Harris^a the shaft of the Avery Salt Mining Co. is 21 feet by 10 feet and 518 feet deep. It is divided into two hoisting shafts and one ventilating shaft. The galleries are 30 feet wide and are run in two directions at right angles to each other, pillars 30 feet square being left as supports.

The salt is conveyed to the foot of the shaft in small cars drawn on a narrow-gage track by horses and mules. The cars are put on the platform of the cage, hoisted to the top floor of the mill, and dumped by hand. The heavy crushing is therefore done at the top of the mill instead of at the foot of the shaft as at Grande Cote. After preliminary crushing the salt is further ground, screened, and winnowed to drive off the salt dust, which tends to deliquesce and thus cement together the larger salt grains. The various grades of salt produced are similar to those produced at Grande Cote, and are used for substantially the same purposes. (See p. 135.)

^a Harris, G. D., Rock salt. Louisiana Geol. Survey Rept. for 1907, Bull. 7, 1908, p. 17.

USEFUL TABLES CONNECTED WITH THE SALT INDUSTRY.

In the following pages are given certain tables relating to (1) the solubility of sodium chloride and other salts, (2) the chlorine content, salinity, and specific gravity of sea water at various concentrations, (3) atomic weight of elements common in saline solutions, (4) factors for converting radicles to compounds, and (5) comprehensive conversion tables for salt solutions.

It is believed that these tables will prove of interest and value to all students of the chemistry of salines in general.

Solubility of certain salts^a

Salt	Temper- ature	Amount of pure com- pound without water of crystallization	
		Dissolved in 100 grams of water	Dissolved in 100 cc of the solution
Sodium chloride (NaCl)	0	35.7	<i>Grams</i>
	10	35.5	
	25	36.12	
	30	37.0	
	100	39.8	
Sodium sulphate (Na ₂ SO ₄ 10H ₂ O)	0	5.0	<i>Grams</i>
	25	28.0	
Sodium sulphate (Na ₂ SO ₄ 7H ₂ O)	0	19.5	-
	25	53.0	
Sodium bromide (NaBr)	0	66.0	-
	20	77.0	
Sodium iodide (NaI 2H ₂ O)	0	155.7	-
	25	184.2	
Potassium chloride (KCl)	0	27.6	-
	25	35.5	
Potassium sulphate (K ₂ SO ₄)	0	7.35	-
	25	10.75	
Potassium bromide (KBr)	0	53.5	-
	25	67.7	
Potassium iodide (KI)	0	127.5	-
	25	145.0	
Calcium chloride (CaCl ₂ 6H ₂ O)	0	59.5	0 1739
	25	91.0	
Calcium sulphate (CaSO ₄ 2H ₂ O)	0		2080
	25		<i>b</i> 426
	35		<i>c</i> 569
	25		<i>d</i> 1620
	25		<i>e</i> 1471
	25		<i>f</i> 666
	25		<i>g</i> 660
Magnesium sulphate (MgSO ₄ 7H ₂ O)	0	26.9	-
	25	38.5	
Magnesium chloride (MgCl ₂ 6H ₂ O)	0	52.8	-
	25	56.7	
Magnesium bromide (MgBr ₂ 8H ₂ O)	0	91.9	-
	25	97.6	
Magnesium iodide (MgI ₂ 8H ₂ O)	0		<i>h</i> 54.4
	25		

^a Siedell, Atherton, *Handbook of solubilities*, New York, 1907, pp 235-264.

^b Solution containing 8.5 grams per liter of MgCl₂.

^c Solution containing 19.8 grams per liter of MgCl₂.

^d Solution containing 3.2 grams per liter of MgSO₄.

^e Solution containing 10.64 grams per liter of MgSO₄.

^f Solution containing 91.15 grams per liter of NaCl.

^g Solution containing 284.17 grams per liter of NaCl.

^h Dissolved in 100 grams of the aqueous solution.

Chlorine content, salinity, and specific gravity of sea water at various concentrations ^a

Chlorine per kilogram	Salinity per kilogram	Specific gravity (0/4°)	Chlorine per kilogram	Salinity per kilogram	Specific gravity (0/4°)
1.00	1.84	1.00140	19.60	35.41	1.02846
2.00	3.64	1.00287	19.65	35.50	1.02833
3.00	5.45	1.00483	19.70	35.59	1.02830
4.00	7.26	1.00719	19.75	35.67	1.02827
5.00	9.06	1.00726	19.80	35.77	1.02825
6.00	10.86	1.00871	19.85	35.86	1.02822
7.00	12.67	1.01016	19.90	35.95	1.02819
8.00	14.47	1.01151	19.95	36.03	1.02816
9.00	16.28	1.01307	20.00	36.13	1.02814
10.00	18.08	1.01452	20.10	36.31	1.02915
11.00	19.89	1.01597	20.20	36.49	1.02933
12.00	21.69	1.01742	20.30	36.67	1.02947
13.00	23.50	1.01887	20.40	36.85	1.02962
14.00	25.30	1.02032	20.50	37.03	1.02977
15.00	27.11	1.02177	20.60	37.21	1.02991
16.00	28.92	1.02322	20.70	37.39	1.03005
17.00	30.72	1.02468	20.80	37.57	1.03020
18.00	32.52	1.02613	20.90	37.75	1.03035
19.00	34.33	1.02758	21.00	37.94	1.03049
19.10	34.69	1.02770	21.00	38.01	1.03122
19.20	34.99	1.02787	22.00	38.74	1.03195
19.30	34.87	1.02802	22.50	40.64	1.03208
19.40	35.05	1.02816	23.00	41.55	1.03341
19.50	35.23	1.02831			

^a Knudsen, Martin, Hydrographische Tabellen, Copenhagen, 1911

Atomic weights of elements common in saline solutions ^a

Element	Symbol	Atomic weight	Element	Symbol	Atomic weight
Aluminum.	Al	27.1	Magnesium	Mg	24.32
Boron.	B	11.0	Oxygen	O	16.00
Bromine.	Br	79.92	Phosphorus	P	31.04
Calcium.	Ca	40.07	Potassium	K	39.10
Carbon.	C	12.00	Silicon	Si	28.3
Chlorine.	Cl	35.46	Sodium	Na	23.00
Iodine.	I	126.92	Sulphur	S	32.07
Iron.	Fe	55.84			

^a Annual Report of the International Committee on Atomic Weights, 1915, Jour Am Chem Soc, vol 36, 1914, p 1555

Factors for converting radicles to compounds ^a

Radicle	Compound	Factor	Radicle	Compound	Factor
Na	NaCl	2.533	Cl	NaCl	1.650
	Na ₂ O	1.496		KCl	2.103
	Na ₂ SO ₄	3.084		MgCl ₂	1.419
	Na ₂ SO ₄ ·10H ₂ O	6.992		MgCl ₂ ·6H ₂ O	2.347
	Na ₂ SO ₄ ·7H ₂ O	5.820		CaCl ₂	1.563
	Na ₂ CO ₃	2.301		CaCl ₂ ·6H ₂ O	3.090
	Na ₂ HCO ₃	3.457			
	NaI	6.502		NaBr	1.288
	Na ₂ ·2H ₂ O	5.065		NaBr·2H ₂ O	1.739
K	Na ₂ Br	4.469	Br	Na ₂ Br ₂	1.459
	Na ₂ Br·2H ₂ O	6.035		MgBr ₂	1.32
	KCl	1.906		MgBr ₂ ·6H ₂ O	1.825
	K ₂ O	1.294		CaBr ₂	1.251
	K ₂ SO ₄	2.225			
Mg	K ₂ CO ₃	1.767	I	NaI	1.183
	K ₂ HCO ₃	2.550		NaI·2H ₂ O	1.405
	KI	4.932		KI	1.308
	KBr	3.044		MgI ₂	1.695
	MgCl ₂	3.090		MgI ₂ ·8H ₂ O	1.514
	MgCl ₂ ·6H ₂ O	8.376		CaI ₂	1.158
	MgO	1.659			
	MgSO ₄	4.958			
	MgSO ₄ ·7H ₂ O	11.151			
Ca	MgCO ₃	3.471	SO ₄	Mg ₂ SO ₄	1.814
	Mg(HCO ₃) ₂	6.028		Mg ₂ SO ₄ ·7H ₂ O	3.353
	Mg ₂ I ₂	11.449		Mg ₂ SO ₄ ·7H ₂ O	2.792
	Mg ₂ ·8H ₂ O	17.285		CaSO ₄	1.405
	Mg ₂ Br ₂	9.932		CaSO ₄ ·2H ₂ O	1.417
	Mg ₂ Br ₂ ·6H ₂ O	12.035		CaSO ₄ ·2H ₂ O	1.702
	CaCl ₂	2.763		Na ₂ CO ₃	1.763
	CaCl ₂ ·6H ₂ O	5.467		K ₂ CO ₃	2.304
	CaO	1.399		CaCO ₃	1.663
HCO ₃	CaSO ₄	3.398		MgCO ₃	1.405
	Ca ₂ O·2H ₂ O	4.307	HCO ₃	NaHCO ₃	1.378
	CaCO ₃	2.468		KHCO ₃	1.611
	Ca(HCO ₃) ₂	4.045		Mg(HCO ₃) ₂	1.399
	Ca ₂ I ₂	7.331		Ca(HCO ₃) ₂	1.328
	CaBr ₂	4.990			

^aCalculated by R. B. Dole, from Annual Report of the International Committee on Atomic Weights, 1937, which differ little from those of 1915.

Conversion tables for salt solutions ^a

Salimeter degrees.	Baumé degrees	Specific gravity	Per cent of salt.	Weight of a gallon of this brine in pounds of 7,000 grains each	Pounds of salt in a gallon of brine or 231 cubic inches	Gallons of brine required for a bushel of salt.	Pounds of water to be evaporated to produce a bushel of salt.	Pounds of coal required to produce a salt, 1 pound of coal evaporating 6 pounds of water	Bushels of salt that can be made with a ton of coal of 2,000 pounds
1	0 26	1.002	0 265	8 347	0 022	2,531 40	21,076 00	3,512 67	0 569
2	52	1.033	530	8 356	.014	1,264 40	10,510 00	1,751 71	1 141
3	78	1.095	795	8 372	.066	841 30	6,988 02	1,161 67	1 717
4	1 04	1.007	1 060	8 389	.088	629 72	5,227 03	871 17	2 295
5	1 30	1.009	1 325	8 406	.111	502 77	4,170 41	695 06	2 877
6	1 56	1.010	1 590	8 414	.133	418 56	3,466 01	577 66	3 462
7	1 82	1.012	1 855	8 431	.156	358 06	2,962 87	493 81	4 050
8	2 08	1.014	2 120	8 447	.179	312 68	2,585 50	430 91	4 611
9	2 34	1.016	2 385	8 462	.201	277 39	2,282 00	382 00	5 255
10	2 60	1.017	2 550	8 472	.224	249 41	2,057 20	342 86	5 833
11	2 86	1.019	2 913	8 489	.247	226 29	1,865 09	310 84	6 434
12	3 12	1.021	3 180	8 506	.270	207 02	1,705 00	284 16	7 038
13	3 38	1.023	3 445	8 522	.293	190 72	1,569 54	261 59	7 615
14	3 64	1.025	3 710	8 339	.316	176 76	1,453 43	242 23	8 256
15	3 90	1.026	3 975	8 547	.339	164 81	1,352 80	225 46	9 488
16	4 16	1.028	4 240	8 564	.363	154 21	1,264 75	210 79	10 109
17	4 42	1.030	4 505	8 581	.386	144 86	1,187 06	197 84	10 733
18	4 68	1.022	4 770	8 597	.410	136 54	1,118 00	186 33	11 361
19	4 94	1.034	5 035	8 614	.433	129 11	1,056 21	176 03	12 992
20	5 20	1.035	5 300	8 622	.457	122 33	1,000 60	166 76	13 611
21	5 46	1.037	5 565	8 639	.480	116 47	950 28	153 34	14 267
22	5 72	1.039	5 830	8 656	.504	110 96	904 54	150 73	15 266
23	5 98	1.041	6 095	8 672	.528	105 93	862 78	143 79	15 903
24	6 24	1.013	6 360	8 689	.552	101 33	820 50	137 41	14 534
25	6 50	1.045	6 625	8 706	.576	97 09	789 28	131 54	15 203
26	6 76	1.046	6 890	8 714	.600	93 26	756 77	126 12	15 856
27	7 02	1.048	7 155	8 731	.624	89 64	726 66	121 11	16 513
28	7 28	1.050	7 420	8 747	.649	86 27	698 71	116 45	17 173
29	7 54	1.052	7 685	8 764	.673	83 14	672 69	112 11	17 838
30	7 80	1.054	7 950	8 781	.698	80 21	648 40	108 06	18 507
31	8 06	1.056	8 215	8 797	.722	77 48	625 67	104 27	19 179
32	8 32	1.058	8 480	8 814	.747	74 92	604 37	100 72	19 855
33	8 58	1.059	8 745	8 822	.771	72 53	584 36	97 39	20 535
34	8 84	1.061	9 010	8 839	.795	70 31	565 53	94 25	21 218
35	9 10	1.063	9 275	8 856	.821	68 17	547 77	91 29	21 906
36	9 36	1.065	9 540	8 872	.846	66 15	531 00	88 50	22 598
37	9 62	1.067	9 805	8 889	.871	64 24	515 13	85 85	23 294
38	9 88	1.069	10 070	8 905	.896	62 44	500 10	83 35	23 983
39	10 14	1.071	10 335	8 922	.922	60 72	485 84	80 97	24 699
40	10 40	1.073	10 600	8 939	.947	59 09	472 30	78 71	25 407
41	10 66	1.075	10 865	8 955	.973	57 54	459 41	76 56	26 120
42	10 92	1.077	11 130	8 972	.998	56 07	447 14	74 52	26 837
43	11 18	1.079	11 395	8 989	1 024	51 66	435 44	72 57	27 558
44	11 44	1.081	11 660	9 005	1 050	53 32	424 27	70 71	28 238
45	11 70	1.083	11 925	9 022	1 075	52 04	413 60	68 93	29 013
46	11 96	1.085	12 190	9 039	1 101	50 82	403 39	67 23	29 747
47	12 22	1.087	12 455	9 055	1 127	49 64	388 61	65 60	30 486
48	12 48	1.089	12 720	9 072	1 154	48 52	384 25	64 04	31 229
49	12 74	1.091	12 985	9 089	1 180	47 44	375 26	62 54	31 977
50	13 00	1.093	13 250	9 105	1 205	46 41	366 64	61 10	32 729
51	13 26	1.095	13 515	9 122	1 232	45 42	358 34	59 72	33 487
52	13 52	1.097	13 780	9 139	1 259	44 46	350 38	58 39	34 247
53	13 78	1.100	14 045	9 164	1 287	43 50	342 71	59 11	35 015
54	14 04	1.102	14 310	9 180	1 313	42 62	335 35	55 89	35 783
55	14 30	1.104	14 575	9 197	1 340	41 77	328 21	54 70	36 560
56	14 56	1.108	14 840	9 214	1 367	40 95	321 35	53 55	37 341
57	14 82	1.108	15 105	9 230	1 394	40 16	314 74	52 45	38 126
58	15 08	1.110	15 370	9 247	1 421	39 39	308 34	51 39	38 917
59	15 34	1.112	15 635	9 264	1 448	38 66	302 17	50 36	39 712
60	15 60	1.114	15 900	9 280	1 475	37 94	296 21	49 36	40 512
61	15 86	1.116	16 155	9 297	1 502	37 26	290 43	48 40	41 317
62	16 12	1.118	16 430	9 314	1 530	36 59	284 84	47 47	42 129
63	16 38	1.121	16 695	9 339	1 559	35 91	279 42	46 57	42 945
64	16 64	1.123	16 960	9 355	1 586	35 29	274 18	45 69	43 765
65	16 90	1.125	17 225	9 372	1 614	34 68	269 10	44 85	44 591
66	17 16	1.127	17 490	9 389	1 642	34 10	264 18	44 03	45 423
67	17 42	1.129	17 755	9 405	1 670	33 53	259 40	43 23	46 260
68	17 68	1.131	18 020	9 422	1 697	32 98	254 76	42 46	47 102

^a Englehardt, F. E., Annual report of Onondaga Salt Springs, for 1883, 1884, pp 36-37.

Conversion tables for salt solutions—Continued.

Salimeter degrees.	Baumé degrees.	Specific gravity.	Per cent of salt.	Weight of a gallon of this brine in pounds of 7,000 grams each	Pounds of salt in a gallon of brine of 231 cubic inches	Gallons of brine required for a bushel of salt	Pounds of water to be evaporated to produce a bushel of salt	Pounds of coal required to produce a bushel of salt, 1 pound of coal evaporating 6 pounds of water	Bushels of salt that can be made with a ton of coal of 2,000 pounds
69	17 94	1 133	18 285	9 439	1 725	32 44	250 26	41 71	47 949
70	18 20	1 136	18 550	9 464	1 755	31 89	245 88	40 98	48 802
71	18 46	1 138	18 818	9 480	1 783	31 39	241 63	40 27	49 662
72	18 72	1 140	19 080	9 497	1 812	30 90	237 50	39 55	50 526
73	18 98	1 142	19 345	9 514	1 840	30 42	233 47	38 91	57 397
74	19 24	1 144	19 610	9 530	1 868	29 96	229 56	38 26	52 272
75	19 50	1 147	19 875	9 555	1 899	29 48	225 76	37 62	53 153
76	19 76	1 149	20 140	9 572	1 927	29 04	222 05	37 00	54 041
77	20 02	1 151	20 405	9 580	1 956	28 62	218 44	36 40	54 934
78	20 28	1 154	20 670	9 614	1 987	28 17	214 92	35 82	55 834
79	20 54	1 156	20 935	9 630	2 016	27 77	211 49	35 24	56 739
80	20 80	1 158	21 200	9 647	2 045	27 38	208 14	34 69	57 650
81	21 06	1 160	21 465	9 664	2 074	26 99	204 88	34 14	58 568
82	21 32	1 163	21 730	9 689	2 105	26 59	201 70	33 61	59 471
83	21 58	1 165	21 995	9 705	2 134	26 23	198 60	33 10	60 421
84	21 84	1 167	22 260	9 722	2 164	25 87	195 57	32 59	61 359
85	22 10	1 170	22 525	9 747	2 195	25 50	192 61	32 10	62 301
86	22 36	1 172	22 790	9 764	2 225	25 16	189 72	31 62	63 250
87	22 62	1 175	23 055	9 780	2 256	24 81	186 89	31 14	64 206
88	22 88	1 177	23 320	9 805	2 286	24 48	184 13	30 68	65 168
89	23 14	1 179	23 585	9 822	2 316	24 17	181 44	30 24	66 137
90	23 40	1 182	23 850	9 847	2 348	23 84	178 89	29 80	67 113
91	23 66	1 184	24 115	9 864	2 378	23 54	176 22	29 37	68 096
92	23 92	1 188	24 380	9 880	2 408	23 24	173 69	28 94	69 085
93	24 18	1 189	24 645	9 905	2 441	22 93	171 22	28 53	70 086
94	24 44	1 191	24 910	9 922	2 471	22 65	168 80	28 13	71 086
95	24 70	1 194	25 175	9 947	2 504	22 38	166 44	27 73	72 105
96	24 96	1 196	25 440	9 964	2 534	22 00	164 12	27 35	73 114
97	25 22	1 198	25 705	9 980	2 565	21 82	161 85	26 97	74 140
98	25 48	1 201	25 970	10 005	2 598	21 55	159 63	26 60	75 172
99	25 74	1 203	26 235	10 022	2 629	21 29	157 45	26 24	76 212
100	26.00	1 205	26 500	10 039	2 660	21 04	155 32	25.88	77 259

PUBLICATIONS ON MINERAL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 45. Sand available for filling mine workings in the northern anthracite coal basin of Pennsylvania, by N. H. Darton. 1912. 33 pp., 8 pls., 5 figs.

BULLETIN 64. The titaniferous iron ores in the United States, their composition and economic value, by J. T. Singewald, jr. 1913. 145 pp., 16 pls., 3 figs.

BULLETIN 70. A preliminary report on uranium, radium, and vanadium, by R. B. Moore and K. L. Kithil. 1913. 100 pp., 2 pls., 2 figs.

BULLETIN 73. Brass furnace practice in the United States, by H. W. Gillett. 1914. 298 pp., 2 pls., 23 figs.

BULLETIN 81. The smelting of copper ores in the electric furnace, by D. A. Lyon and R. M. Keeney. 1915. 80 pp., 6 figs.

BULLETIN 84. Metallurgical smoke, by C. H. Fulton. 1915. 94 pp., 6 pls., 15 figs

BULLETIN 85. Analyses of mine and car samples of coal collected in the fiscal years 1911 to 1913, by A. C. Fieldner, H. I. Smith, A. H. Fay, and Samuel Sanford. 1914. 444 pp., 2 figs.

BULLETIN 92. Feldspars of the New England and Northern Appalachian States, by A. S. Watts. 180 pp., 3 pls., 22 figs.

BULLETIN 104. Extraction and recovery of radium, uranium, and vanadium from carnotite, by C. L. Parsons, R. B. Moore, S. C. Lind, and O. C. Schaefer. 1915. 124 pp., 14 pls., 9 figs.

BULLETIN 106. The technology of marble quarrying, by Oliver Bowles. 1916. 174 pp., 12 pls., 33 figs.

BULLETIN 122. The principles and practice of sampling metallic metallurgical materials, with special reference to the sampling of copper bullion, by Edward Keller. 1916. 101 pp., 13 pls., 31 figs.

BULLETIN 124. Sandstone quarrying in the United States, by Oliver Bowles. 1917. 143 pp., 6 pls., 19 figs.

BULLETIN 128. Refining and utilization of Georgia kaolins, by I. E. Sproat. 1916. 55 pp., 5 pls., 11 figs.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps with tungsten filaments, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 43. The effect of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 50. Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 76. Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

TECHNICAL PAPER 88. The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915. 29 pp., 1 pl., 4 figs.

TECHNICAL PAPER 95. Mining and milling of lead and zinc ores in the Wisconsin district, Wisconsin, by C. A. Wright. 1915. 39 pp., 2 pls., 5 figs.

TECHNICAL PAPER 102. Health conservation at steel mills, by J. A. Watkins. 1916. 36 pp.

TECHNICAL PAPER 110. Monazite, thorium, and mesothorium, by K. L. Kithil. 1915. 32 pp., 1 fig.

TECHNICAL PAPER 111. Safety in stone quarrying, by Oliver Bowles. 1915. 48 pp., 5 pls., 4 figs.

TECHNICAL PAPER 126. The casting of clay wares, by T. G. McDougal. 1916. 26 pp., 6 figs.

TECHNICAL PAPER 136. Safe practice at blast furnaces, by F. H. Willcox. 1916. 73 pp., 1 pl., 43 figs.

TECHNICAL PAPER 143. Ores of copper, lead, gold, and silver, by C. H. Fulton. 1916. 41 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 11. The purchase of coal by the Government under specifications, with analyses of coal delivered for the fiscal year 1908-9, by G. S. Pope. 80 pp., 10 cents.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer, and S. J. Hoffman. 1911. 22 pp., 6 figs. 5 cents.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 22. Analyses of coals in the United States, with descriptions of mine and field samples collected between July 1, 1904, and June 30, 1910, by N. W. Lord, with chapters by J. A. Holmes, F. M. Stanton, A. C. Fieldner, and Samuel Sanford. 1912. Part I, Analyses, pp. 1-321; Part II, Descriptions of samples, pp. 321-1129. 85 cents.

BULLETIN 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. 20 cents.

BULLETIN 38. The origin of coal, by David White and Reinhardt Thiessen, with a chapter on the formation of peat, by C. A. Davis. 1913. 390 pp., 54 pls. 80 cents.

BULLETIN 41. Government coal purchases under specifications, with analyses for the fiscal year 1909-10, by G. S. Pope, with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls., 9 figs. 15 cents.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 28 figs. 20 cents.

BULLETIN 47. Notes on mineral wastes, by C. L. Parsons. 1912. 44 pp. 5 cents.

BULLETIN 53. Mining and treatment of feldspar and kaolin in the Southern Appalachian region, by A. S. Watts. 1913. 170 pp., 16 pls., 12 figs. 35 cents.

BULLETIN 63. Sampling coal deliveries and types of Government specifications for the purchase of coal, by G. S. Pope. 1913. 68 pp., 4 pls., 3 figs. 10 cents.

BULLETIN 71. Fullers' earth, by C. L. Parsons. 1913. 38 pp. 5 cents.

BULLETIN 107. Prospecting and mining of copper ore at Santa Rita, N. M., by D. F. MacDonald and Charles Enzian. 1916. 122 pp., 10 pls., 20 figs. 25 cents

BULLETIN 108. Melting aluminum chips, by H. W. Gillett and G. M. James. 1916. 88 pp. 10 cents.

BULLETIN 111. Molybdenum, its ores and their concentration, with a discussion of market, prices, and uses, by F. W. Horton. 1916. 132 pp., 18 pls., 2 figs. 30 cents

BULLETIN 121. The history and development of gold dredging in Montana, by Hennen Jennings, with a chapter on placer-mining methods and operating costs, by Charles Janin. 1916. 64 pp., 29 pls., 1 fig. 30 cents

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp. 5 cents

TECHNICAL PAPER 26. Methods for the determination of the sulphur content of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp., 1 fig. 5 cents.

TECHNICAL PAPER 41. The mining and treatment of lead and zinc ores in the Joplin district, Mo., a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs. 5 cents.

TECHNICAL PAPER 60. The approximate melting points of some commercial copper alloys, by H. W. Gillett and A. B. Norton. 1913. 10 pp., 1 fig. 5 cents.

TECHNICAL PAPER 90. Metallurgical treatment of the low-grade and complex ores of Utah, a preliminary report by D. A. Lyon, R. H. Bradford, S. S. Arentz, O. C. Ralston, and C. L. Larson. 1915. 40 pp. 5 cents.

TECHNICAL PAPER 93. Graphic studies of ultimate analyses of coals, by O. C. Ralston, with a preface by H. C. Porter. 1915. 41 pp., 3 pls., 6 figs. 10 cents

TECHNICAL PAPER 109. Composition of the natural gas used in 25 cities, with a discussion of the properties of natural gas, by G. A. Burrell and G. G. Oberfell. 1915. 22 pp. 5 cents.

INDEX.

A.	Page	Page	
Air-lift system of raising brine.....	63	Bromine in bitters, proportion of	47, 48
Akron, Ohio, manufacture of salt at.....	74	in brines, proportion of	82
Alberger process of making salt, details of.....	68	salts associated with.....	85
precipitation of lime in.....	121	manufacture of, apparatus for	89
salt made by, view of.....	118	figure showing.....	90
Alpena, Mich., salt deposits at.....	11	extent of.....	81
Alum as precipitant, use of.....	77	methods for.....	84, 86, 88, 89, 91, 92
Alvarado, Cal., lifting of salt at, view of.....	50	patents for.....	80, 81, 93
manufacture of salt at.....	11, 100	solidified, preparation of.....	95
sea water at, density of.....	12	uses of	84, 94, 95
Anthony, Kans., manufacture of salt at.....	76	Bromine still, construction of	85, 86
salt deposits at.....	19	Brooks Saline, Texas, salt deposits in.....	26, 27
Arfis, Cal. <i>See</i> Baumberg, Cal.		C.	
Arizona, salt deposits of.....	5, 31	Calcium chloride from natural brines, analyses	
<i>See also</i> localities named		of	97
Armagosa River, salt deposits in.....	35	recovery of, methods for	95, 96
Averys Island, La. <i>See</i> Petit Anse, La		solubility of	137
B			
Bailey, R. K., acknowledgments to	2	Calcium in bitters, proportion of	47, 48
cited.....	49	in Great Salt Lake water, proportion of	50
Barberton, Ohio, utilization of brines at.....	74	in natural brines, proportion of	82
Barium salts in brines, occurrence of.....	77	Calcium sulphate, formation of, in open-kettle	
removal of	77	process	54
Barstow, E. C., method for manufacture of		in brines, difficulties caused by	105
bromine.....	88, 89	solubility of	137
Baumberg, Cal., production of salt at.....	41	<i>See also</i> Gypsum.	
Bay City, Mich., analysis of brine from	82, 83	California, manufacture of salt in	40, 41
manufacture of bromine at	81, 85, 86	salt deposits of	5, 32-37
manufacture of salt at	71-73	salt industry of, relative importance of	32
Bishop, I. P., cited.....	8	<i>See also</i> localities named	
Butters from sea water, analyses of	47, 48	Chatard, T. M., cited.....	119, 121, 122
specific gravity of	48	Chlorine gas for manufacture of bromine, use	
utilization of	iv, 46, 47	of	91, 92
Blake, W. P., cited.....	31	Chlorine in bitters, proportion of	47, 48
Bleaching powder, liberation of bromine by	92	in natural brines, proportion of	82
Blount, B., on manufacture of bromine	94	in sea water, proportion of	138
Bloxam, A. G., on manufacture of bromine	94	Clarke, F. W., cited.....	49
Bownocker, J. A., cited.....	15	Cleveland, Ohio, manufacture of salt at	62, 74, 75, 100
Bradford, Pa., salt well near, record of	17	Coal for salt manufacture, amount of	140, 141
Brecht evaporator, details of	108, 109	<i>See also</i> Fuel	
view of	108	Cole, L. H., cited.....	106, 111
Brine salt, production and value	120	Colorado City, Tex., salt deposits at	28
Brines, natural, analyses of	82, 83	Combination salt, manufacture of	118
manufacture of bromine from	84	Condenser, lead, in bromine manufacture, ob-	
methods of lifting	63	jections to	87
occurrence of	2	Conveyors, belt, objections to	67
<i>See also</i> States and localities named		Cortland, Ohio, salt deposits of, depth of	12
removal of gypsum from	121	Crane vacuum pan, construction of	109
removal of iron in	54, 55, 64	view of	110
		Crystallization of salts, fractional, factors gov-	
		erning	61

	Page		Page.
Crystallizing ponds, area of, factors governing.....	43	Grainers—Continued	73, 74
ing.....	43	dimensions of.....	71
view of.....	44, 46	heating of.....	69
Cuyerville, N. Y., mining of rock salt at.....	126	operation of.....	123
D.		results of.....	65, 73
Dairy, preparation of salt for.....	117	output of, factors governing.....	78
Danby, Cal., salt deposits near.....	36	types of.....	70
Dawson, A. G., acknowledgments to.....	2	views of.....	24, 25
Death Valley, Cal., salt deposits in.....	34	Grand Saline, Tex., manufacture of salt at.....	25, 26
Del Rey, Mich., manufacture of salt near.....	73, 74, 100	salt deposits in.....	76
Detroit, Mich., manufacture of salt near.....	73, 74	salt wells at, records of.....	124, 135
mining of rock salt at.....	124, 126, 127	salt deposits on.....	21, 22
Deussen, A., cited.....	23	Great Salt Lake, water of, analyses of.....	49
Direct heat evaporation. <i>See</i> Open kettle		character of.....	50
process of evaporation.....		manufacture of salt from.....	51, 52
Dole, R. B., acknowledgments to.....	2	Gypsum in brines, difficulties caused by.....	105
Dow, H. H., methods for manufacture of bromine.....	91-93	removal of.....	121
Drier, construction and operation.....	117	<i>See also</i> Calcium sulphate; Lime.	
rotary cylinder, view of.....	118	H	
Duncan, J. H., manufacture of salt by.....	98	Halite. <i>See</i> Salt	
Duncan, J. M., manufacture of salt by.....	98	Halite, N. Y., mining of rock salt at.....	124, 126
Durham, E. B., experiments of.....	47	salt plant at, flow sheet of, figure showing.....	127
E.		Harris, G. D., cited.....	22, 23, 136
East Lake, Mich., manufacture of salt near.....	70	Hartford, W. Va., analysis of brine from.....	82, 83
Eckel, E. C., on salt deposits of Virginia.....	18	grainers at, view of.....	70
Ecrose, Mich., manufacture of salt near.....	73, 74, 100	manufacture of bromine at.....	81
Electricity, liberation of bromine by.....	92	salt well at, depth of.....	14
Ellsworth, Kans., manufacture of salt at.....	76	Heat, waste, in salt manufacture, utilization of.....	62
Epsom salts from bittern, recovery of.....	47	Hicks, W. B., acknowledgments to.....	2
Evaporation of salt, methods of.....	52	Hutchinson, Kans., manufacture of salt at.....	59, 60, 76, 100
<i>See also</i> Direct heat evaporation, Solar evaporation; Steam evaporation, Vacuum-pan process.		open-pan room at, view of.....	60
Evaporators, efficiency of, factors governing.....	122	salt deposits at.....	20
<i>See also</i> Brecht evaporator; Craney vacuum pan, Lillie evaporator, Maniste evaporator, Oscar Krenz pan, Swenson evaporator, Sanborn evaporator, Wheeler evaporator, Zaremba evaporator.		Hydraulic pressure, lifting of brine by.....	63, 75
F.		Hydrogen sulphide in brine, elimination of.....	71
Fairport Harbor, Ohio, utilization of brines at.....	74	I.	
Filer City, Mich., manufacture of salt near.....	70	Idaho, salt deposits in.....	5, 29
Filtering tanks, treatment of brines in.....	79	<i>See also</i> localities named	
Fuel for salt making.....	56, 60, 76, 79, 80	Intake pond, purpose of.....	43
costs of.....	120	Iron in brine, removal of.....	54, 55, 64, 69, 75
<i>See also</i> Coal		Ithaca, N. Y., manufacture of salt at.....	62, 99
G.		salt deposits at.....	6, 8
Gale, H. S., acknowledgments to.....	2	K	
Germany, deposits of bromine in.....	84	Kanopolis, Kans., salt bed at, section of.....	132, 133
Gilbert, G. K., cited.....	5, 49, 51	salt deposits at.....	19, 20
Grainer process, details of.....	65	mining of.....	124, 131, 134
principle underlying.....	61	salt mine at, equipment of.....	131, 134
relative efficiency of.....	122, 123	shaft in, method of sinking.....	133, 134
salt produced by, character of.....	118	section of.....	133
<i>See also</i> Alberger process.		salt plant at, view of.....	108
Grainers, cleaning of.....	70	Kansas, manufacture of salt in.....	55-57
construction of.....	68, 74, 76	method of lifting brine in.....	63
description of.....	68	rock salt in, commercial grades of.....	134, 135
Kingman, Kans., salt deposits at.....	20, 124	salt deposits of.....	5, 19, 20

L.	Page.	Page.
Labor in salt making, character of.....	120, 121	
Lakewood, Ohio, analysis of brine from.....	82, 83	
Le Roy, N. Y., salt deposits at.....	6	
Lillie, S. M., acknowledgments to.....	2	
method of making combination salt.....	118	
Lillie evaporator, cleaning of, factors in.....	107	
details of.....	106, 107	
salt made in, view of.....	118	
views of.....	106, 108	
Lime, treatment of brine with.....	54,	
55, 57, 64, 69, 74, 75, 121		
Long Beach, Cal., harvesting salt at.....	45	
view of.....	48	
salt ponds at, view of.....	48	
Louisiana, salt deposits of.....	5, 20-22	
See also localities named.		
Ludington, Mich., salt wells at, depth of.....	70	
record of.....	10	
manufacture of salt at.....	70, 71, 100	
Ludlowville, N. Y., manufacture of salt at.....	99	
salt deposits at.....	7	
Lyons, Kans., manufacture of salt at.....	76, 124, 130	
mining of rock salt at.....	124, 128, 129, 130	
salt deposits at.....	19, 20	
salt mine at, equipment of.....	130	
figure showing.....	128	
M.		
McDonald, Pa., salt well near.....	17	
Magnesium chloride, recovery of.....	47	
solubility of.....	137	
Magnesia salts, recovery of.....	43	
Magnesium in brines, proportion of.....	47, 48, 82	
in Great Salt Lake water, proportion of.....	50	
Malden, W. Va., analysis of brine from.....	82, 83	
manufacture of bromine at.....	81, 85, 86	
treatment of brines at.....	79, 80	
Manistee, Mich., manufacture of salt at.....	70, 71, 99, 100	
salt deposits at, depth of.....	10, 70	
Manistee evaporator, operation of, details of.....	104, 105	
salt made in, view of.....	118	
Marine City, Mich., manufacture of salt near.....	73, 74, 100	
Mason, W. Va., brines from, analysis of.....	82, 83	
treatment of.....	77, 78	
depth of salt wells at.....	77	
manufacture of bromine at.....	81	
Merrill, F. J. H., cited.....	122	
Michigan, manufacture of bromine in, method for.....	87	
manufacture of salt in.....	55-59, 70	
method of lifting brine in.....	63	
recovery of calcium chloride in.....	96, 97	
salt deposits of.....	5, 9	
salt industry in, extent of.....	9, 70	
See also localities named.		
Midland, Mich., analyses of brine from.....	72, 82, 83	
manufacture of bromine at.....	81	
manufacture of salt at.....	71, 72	
Mohave River, salt deposits in.....	36	
Mono Lake, Cal., salt deposits in.....	35	
Mount Eden, Cal., loading salt at, view of.....	48	
manufacture of salt at.....	41	
view of.....	44	
salt ponds at, views of.....	44	
Mount Eden, Cal., loading salt at, view of—Continued		
sea water at, density of.....	42	
windmills at, views of.....	46	
Mount Pleasant, Mich., analyses of brine at.....	72	
manufacture of bromine at.....	81	
manufacture of salt at.....	71, 72	
recovery of calcium chloride at.....	96	
Mud settlers, treatment of brine in.....	77-80	
N.		
Nephi, Utah, salt plant at, view of.....	60	
Nevada, salt deposits in.....	5, 30	
salt industry in.....	30	
See also localities named.		
New Mexico, salt deposits in.....	5, 30, 31	
salt industry in.....	30	
New York, manufacture of salt in.....	55-58, 60, 70	
salt deposits of.....	5-8	
See also places named.		
Newark, Cal., production of salt at.....	41	
O.		
Ohio, manufacture of bromine in.....	85, 86	
method of lifting brine in.....	63	
natural brines in.....	2	
recovery of calcium chloride in.....	95	
salt deposits of.....	5, 11, 12	
salt industry in.....	11	
See also localities named.		
Oklahoma, salt deposits in.....	29	
salt industry in.....	28	
Open-kettle process of evaporation, description of.....	54, 55	
efficiency of.....	55	
Open-pan process, advantages of.....	57	
apparatus for.....	55, 56	
defect of.....	101	
description of.....	57-59	
Oregon, salt deposits in.....	5, 29	
See also localities named.		
Oscar Krenz pan, construction of.....	109	
view of.....	110	
Ostend Station, Cal., production of salt at.....	41	
Owens Lake, Cal., salts in.....	34	
P.		
Palestine, Tex., manufacture of salt at.....	76	
salt deposits in.....	26	
Pans, open, for salt making, description of.....	55-59	
figure showing.....	56	
See also Vacuum pans.		
Pennsylvania, method of lifting brine in.....	63	
salt deposits of.....	5, 16, 17	
See also localities named.		
Petite Anse, La., mining of rock salt at.....	124, 136	
salt deposits on.....	22, 23	
salt wells on, records of.....	23	
Pittsburgh, Pa., manufacture of salt at.....	75, 76	
salt well near, record of.....	16, 17	
Pohle system of raising brine. <i>See</i> Air lift system.		
Pomeroy, Ohio, manufacture of bromine at.....	81	
natural brine at.....	14, 15	
analysis of.....	82, 83	
treatment of.....	79	

Page.	Page.
Pomeroy, Ohio, manufacture of bromine at—Continued	
salt deposits at.....	13
salt well near, depth of.....	13, 14
Port Huron, Mich., manufacture of salt near.....	73, 74, 100
Potassium chlorate for manufacture of bro- mine.....	86
Potassium in bitterns, proportion of.....	47, 48, 82
recovery of.....	43, 46, 77
Preheating tanks, dimensions of.....	71, 73, 74
heating of brine in.....	64
view of.....	70
Frosser, C. S., cited.....	6
Pumping, method of lifting brine by.....	63
“Purifier” for grainer process, details of.....	68
R.	
Rakers, mechanical, construction of.....	66, 67
figure showing.....	66
use of.....	70
Redmond, Utah, manufacture of salt near.....	80
salt mine near, view of.....	30
Retsof, N. Y., mining of rock salt at.....	124, 125
salt mine in, record of.....	124, 125
Reynolds, John, manufacture of salt by.....	97, 98
Richardson, G. B., cited.....	27
Rittman, Ohio, analysis of brine from.....	82, 83
manufacture of salt at.....	74, 75, 100
Rock salt, grades of.....	130, 131, 134, 135
view of.....	132
market sizes of.....	128
mining and treatment.....	124-127, 130, 131
occurrence of.....	4
production of.....	120
value of.....	120
<i>See also</i> States and localities named.	
Russell, I. C., cited.....	5
Russell, Cal., production of salt at.....	41
S	
St. Charles, Mich., analysis of brine at.....	72, 82, 83
depth of salt wells at.....	71
manufacture of bromine at.....	81, 85, 86
manufacture of salt at.....	71, 72
St. Clair, Mich., manufacture of salt near.....	73, 74, 100
Saginaw, Mich., analysis of brine from.....	82, 83
depth of salt wells at.....	71
manufacture of bromine at.....	81, 85, 86
manufacture of salt at.....	71-73
fuel used for.....	120
Saline Valley, Cal., salt deposits in.....	34
Salt, characteristics of.....	3
harvesting of, views of.....	52
manufacture of, classification of processes for.....	38
investigations of, scope of.....	1, 2
minerals associated with.....	3
occurrence of.....	3, 4
overproduction of.....	119
table, manufacture of.....	117
uses of.....	3
<i>See also</i> Brine salt, Combination salt, Rock salt	
Salt Basin, Tex., salt deposits in.....	27
Salt deposits, character of.....	5
distribution of.....	3-5
<i>See also</i> States and localities named	
Salt industry, machinery used in, development of.....	120, 121
Salt Lake, Cal., salt deposits in.....	36
Saltmaking equipment, deterioration of. iv, 118, 119	
<i>See also</i> equipment named	
Salt ponds, area of.....	43
description of.....	13, 44
lifting of salt from, view of.....	50
views of.....	44, 48
<i>See also</i> Crystallizing ponds	
Salt Sand, W. Va., extent of.....	15
Saltan, Utah, harvesting salt at, views of.....	52
manufacture of salt at.....	32, 51, 52
Salts, deposition of, factors governing.....	61
<i>See also</i> salts named.	
Saltus, Cal., salt deposits near.....	35
Saltville, Va., salt deposits near.....	18, 19
salt well near, record of.....	19
San Diego, Cal., method of harvesting salt at.....	45
see water at, density of.....	42
San Francisco, Cal., manufacture of salt at.....	100
San Francisco Bay, Cal., salt pond at, view of.....	44
San Mateo, Cal., crystallizing ponds at, views of.....	44, 46
manufacture of salt at.....	41, 100
salt plant at, view of.....	50
Sanborn evaporator, construction and opera- tion.....	111
figure showing.....	112
Sandusky, Ohio, salt well near, depth of.....	13
Sea water, bittern from, analyses of.....	47, 48
chlorine content of.....	138
salinity of.....	138
salt from, harvesting of.....	44, 45
view of.....	48
loading of, view of.....	48
milling of.....	46
production of.....	33, 40-43
washing of.....	45, 46
specific gravity of.....	138
Searles Lake, Cal., salts in, description of.....	34
Settling tanks, dimensions of.....	71, 73, 74
view of.....	70
Silver Springs, N. Y., grammers at, view of.....	70
manufacture of salt at.....	99
preheating tanks at, view of.....	70
salt plant at, vacuum pans used in.....	99
settling tanks at, view of.....	70
Sites, Cal., manufacture of salt at.....	33
Slough, view of.....	46
Soda ash, treatment of brine by.....	55, 57, 64, 69, 121
Sodium chlorate, manufacture of bromine by.....	86, 87
Sodium in bitterns, proportion of.....	47, 48
in brine, proportion of.....	50, 82
Sodium sulphate, crystallization of, preven- tion of.....	52
deposits of.....	36
solubility of.....	137
Solar evaporation process, description of.....	39, 40
improved method for.....	40
use of.....	38, 39

Page	Page		
Steam, exhaust, heating of brine by.....	69, 71, 73	Vincent, N. Y., discovery of salt at	6
Steam evaporation process <i>See</i> Alberger process.		Virginia, salt deposits of	5, 18, 19
Stear Saline, Texas, salt deposits in.....	26	<i>See also</i> localities named.	
Stirling, Kans., manufacture of salt at.....	76		
Stone, G. W., on salt deposits of Virginia.....	18		
Sulphuric acid, manufacture of bromine by..	86, 92		
Swanson evaporator, construction and operation.....	109, 110		
figure showing.....	110		
Syracuse, N. Y., manufacture of salt at. 38-40, 52, 53			
views of.....	40		
T.			
Talmage, J. E., cited.....	32		
Texas, salt deposits in.....	5, 23-28		
<i>See also</i> localities named.			
Tully, N. Y., discovery of salt at.....	7		
U.			
U. S. Geological Survey, investigations of....	1		
Utah, salt deposits of.....	5, 32		
salt industry of.....	31		
V.			
Vacuum pans, details of.....	102		
early use of	98, 99		
view of..	118		
section of, figure showing.....	103		
views of.....	102, 104		
<i>See also</i> Lillie evaporator, Manistee evaporator			
Vacuum pan process, apparatus for, details of.....	102, 104		
operation of, details of.....	101, 105		
principles underlying.....	101, 102		
salt produced by, character of.....	100, 118		
use of, extent of.....	99, 100		
Veatch, A. C., cited.....	135		
on salt deposits of Louisiana.....	21, 22		
W.			
Wadsworth, Ohio, manufacture of salt at. 74, 75, 100			
Warsaw, N. Y., discovery of salt at.....	6		
salt plant at, tests in.....	98, 99		
Washing of salt, methods for.....	59		
Watkins, N. Y., manufacture of salt at.....	99		
Weeks Island, La. <i>See</i> Grande Cote, La			
Wells, R. C., experiments of.....	52		
West Virginia, manufacture of bromine in.....	85, 86		
method of lifting brine in.....	63		
natural brines in.....	2		
recovery of calcium chloride in.....	95		
salt deposits in, extent of.....	15		
salt industry in.....	15		
<i>See also</i> localities named.			
Wheeler evaporators, construction of.....	113		
figure showing.....	114		
White, I. C., cited.....	15		
Willards Lake, Cal., salt deposits in.....	36		
Willcox, G. B., acknowledgments to.....	2		
cited.....	62, 66		
experiments of.....	122		
on fuel as factor in costs of salt making..	120		
on relative efficiency of grainer process..	123		
Windmills, pumping of brine by.....	44		
views of.....	46		
Wyandotte, Mich., manufacture of salt near.....	73, 74, 100		
Wyoming, salt deposits of.....	5, 29		
Wyoming, N. Y., discovery of rock salt at...	6		
Z.			
Zaremba evaporator, construction and operation.....	113, 115, 116		
Zuni salt deposits, New Mexico, salt production from.....	30		

